THE SCIENCE OF COLOUR MIXING

DAVID PATERSON

PUBLISHED AT THE OFFICES OF THE
OIL AND COLOURMAN'S JOURNAL

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THE SCIENCE

OF

COLOUR MIXING

ABERDEEN UNIVERSITY PRESS

Frontispiece. **Plate I.**

Fig. 1.

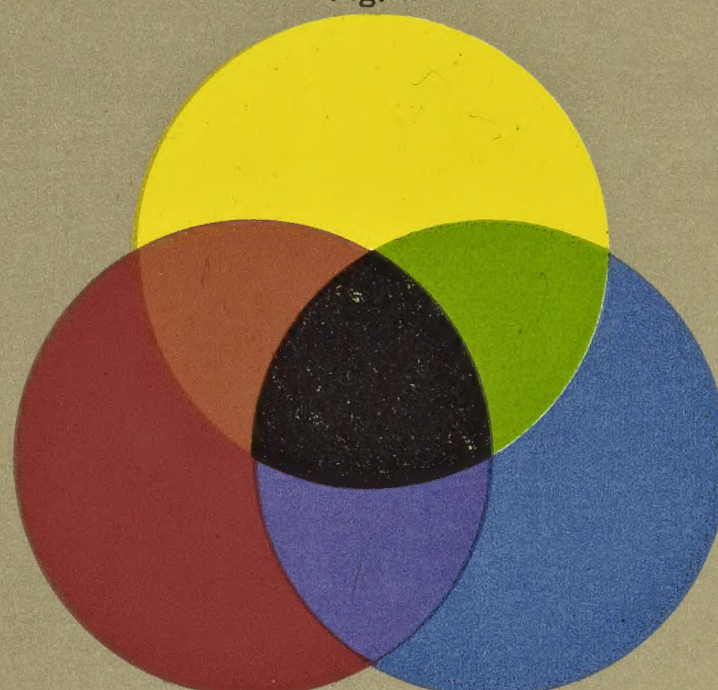

Fig. 2.

Showing Primary, Secondary and Tertiary Colours (Brewster Triad).

[*See* Chapter V.]

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OF

COLOUR MIXING

A MANUAL INTENDED FOR THE USE OF DYERS, CALICO PRINTERS AND COLOUR CHEMISTS

BY

DAVID PATERSON, F.C.S.

AUTHOR OF "COLOUR PRINTING OF CARPET YARNS," ETC.

LONDON

SCOTT, GREENWOOD & CO.

Publishers of the "Oil and Colourman's Journal"

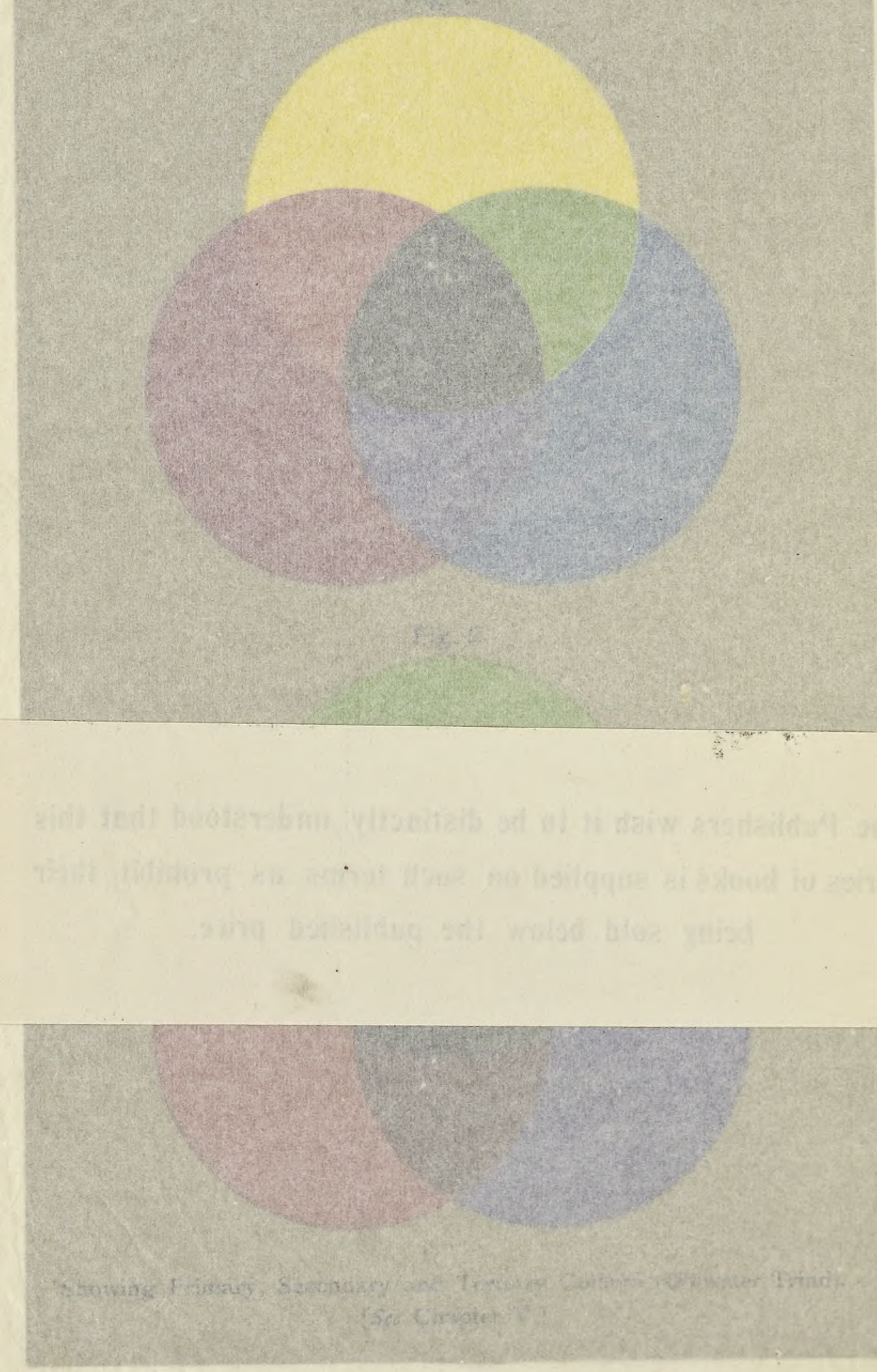
19 LUDGATE HILL, E.C.

1900

Frontispiece. Plate I.

Fig. 1.

Fig. 2.



Showing Primary, Secondary and Tertiary Colours (Chromatic Triads.)
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Dedicated
with Affection
to my
Mother

PREFACE.

In introducing a new book on Colour Science at the present time, one almost requires to do so with a preface of apology, as there are already many excellent works on the subject. But the writer, along with other colourists, has experienced the want of a book dealing in a practical manner with the science of mixing ordinary colours and dyes, and thus made applicable to the common everyday duties of the dyer and the colourist. Theoretical knowledge alone cannot make a successful colour mixer ; but it certainly proves of great value in explaining the true causes of failure, and in directing the conditions which lead to success.

The writer here wishes to express his thanks to the firm of Meister Lucius & Brüning, who have very kindly furnished him with the beautiful dyed patterns to be found in the Appendix.

It is hoped that the treatment of the subject in these pages may prove helpful, not only to the practical colourist, but also to students of our Textile Colleges, by forming a useful complement to their class lectures.

D. P.

Lea Bank,
Rosslyn, Midlothian.
May, 1900.

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THE

SCIENCE OF COLOUR MIXING.

CHAPTER I.

COLOUR A SENSATION—LIGHT WAVES—OBJECTS LUMINOUS AND ILLUMINATED—COLOURS OF ILLUMINATED BODIES—PRODUCTION OF COLOUR BY ABSORPTION—DIFFRACTION—DISPERSION—FLUORESCENCE—COLOURS OF OPAQUE AND TRANSPARENT BODIES—SURFACE COLOUR.

BEFORE proceeding at once to study the principles which underlie the art of mixing colours and dyes, it may be well to review a few elementary facts in regard to colour itself.

§ 1. **COLOUR A SENSATION.**—The science of colour teaches us that what we call colour is merely a sensation, and has no actual existence in the external world. Colour does not form an inherent physical quality of the coloured body. The sensation of colour is produced in a variety of ways, but pre-eminently by the action of Light on the retina of the eye.

Luminous bodies transmit to the light-bearing medium (*luminiferous ether*) a state of excessively rapid vibration, and when these vibrations or "waves" impinge upon the fibres of the optic nerve they produce an excitement of that nerve, which, on being conveyed to the brain, is in some mysterious manner translated into the sensation we call *light* and *colour*. Colour is, however, independent of light,

and may be produced by external means. To "see stars," when the eye receives a blow, is a common enough expression, describing a well-known phenomenon.

If the eyeball be gently pressed with the fingers various different colours are seen, which, as Newton himself described, "resemble the colours of a peacock's tail". As early as 1795, Pfaff, a German physicist, showed that by means of an electric shock on the eyes a series of flashes of light were visible in a totally dark room. The sensation of colour is produced even without external aid, as when the sick person sees certain undefined coloured images floating before the eyes; a fact which, not unusually, gives rise to the idea of seeing ghosts. These few examples go to prove that what we call **light** and **colour** are merely *sensations* within the eye itself, caused by the optic nerve being excited, and have really no external existence.

§ 2. **The Undulatory or Wave Theory of Light** beautifully explains the many complex phenomena of light, but the subject of colour physics lies beyond the scope of this little manual. The light waves are of different lengths, varying from $\frac{1}{33000}$ of an inch to about $\frac{1}{65000}$ of an inch. The longest undulations which affect the nerves within the retina produce the sensation of red, while the shortest produce the sensation of violet. These light waves may also be indicated by their speed, or rapidity of vibration; the waves producing the sensation of red being the slowest, while the most rapid undulations give rise to the sensation of violet. Vibrations which are slower, and therefore longer, than those of the red waves do not affect the eye as light, but are invisible rays of *heat;* while waves that are shorter and more rapid than even the extreme violet are also invisible, and are termed the chemical or *actinic rays* When we speak of slow waves of light we must remember that the term is purely a relative one, as the slowest visible light waves producing the sensation

of red undulate at the immense speed of 390,000,000,000,000 times per second of time. Or in other words, when the sensitive retina of the eye receives 390 billions of beats or vibrations per second, there is produced the sensation of a red colour. If the vibrations increase in rapidity to 770,000,000,000,000 per second the eye perceives a violet colour. Between these two extremes of wave speeds there lies an indefinite variety of waves of different velocities or wave-lengths, all merging into each other, and producing the sensations of orange, yellow, green, blue and violet colours. The shorter the wave-length of the colour the further will it be removed from red.

§ 3. **OBJECTS LUMINOUS AND ILLUMINATED.**—Every object we see is visible either because it gives out light of itself and is therefore self-luminous, or because it reflects light from its surface. The flame of a candle or a lamp, a glowing piece of coal, or the sun, are simple examples of self-luminous objects which emit streams of luminous rays in all directions. Colours are often described as *luminous* when they reflect a large amount of light to the eye, and are clear and bright.

Illuminated bodies are those which reflect borrowed light to the eye, and the quantity and quality of the reflected light vary with each object. A piece of polished metal, or a sheet of glass, for example, when held at the proper angle reflects nearly all its incident light; while, on the other hand, a piece of black velvet reflects no light whatever, and gives to the eye the impression of absolute darkness. The less light the object reflects the less visible it becomes. This may be illustrated in a simple manner by allowing a drop of oil to fall on a piece of white paper. By doing so the innumerable little surface reflections of the paper are destroyed, and the surface therefore can no longer reflect to the eye its incident light. Instead of being *reflected*, the light is *transmitted* through

the oiled part, and is lost to the eye which views the surface. This explains the dark grey appearance of an oiled spot on paper. The paper is thereby rendered less *opaque*, and this simple fact forms the basis of the oiled tracing paper or cloth employed by architects and engineers. An experiment the reverse of this may be made with a piece of colourless transparent glass. The light is freely transmitted through the glass; and, if no ray of light be reflected from its surface, the glass itself will be invisible. If, however, the glass be crushed to a fine powder, so that innumerable little particles of it reflect the light, then it will present the appearance of a white and almost opaque body.

§ 4. **COLOURS OF ILLUMINATED BODIES.**—When daylight is passed through a glass of perfectly pure water, it will appear absolutely clear and colourless; but if the light be transmitted through a thickness of three or four feet of the same pure water, it will be observed that the light is no longer colourless, but has acquired a decidedly bluish tinge. Some of the rays of light, in passing through the water, have become absorbed or quenched, leaving the bluish-coloured rays to predominate. If, to the glass of pure water, we add a few drops of magenta solution, we will observe the same phenomenon of *absorption*, but intensified to a much greater degree. The white light, in passing through the magenta solution, has become robbed of its bright yellow, yellow-green and green rays, and the remaining red, blue and violet-coloured rays combining together in the eye give the sensation of the bluish red or magenta colour. The different quality of the light reflected or transmitted by bodies gives to them their variety of colour. If a substance reflects the rays of the sun all in equal proportion, it will then appear to the eye of the same colour as the light which illuminates it, *i.e.*, white or grey. Thus, objects which are white by daylight appear yellow by yellow light, green by green light, or

red by red light. But, if the body reflects, as in the majority of cases, some rays in larger proportion than others, it will appear coloured, and that colour will consist of the mixture of all the coloured rays which are reflected. We have already seen (§ 2) that white sunlight consists of six principal colours—red, orange, yellow, green, blue and violet—all marvellously blended together, and, by the admixture of these colours in various proportions, is produced all the endless variety and beauty of colour to be found in art and nature. But if the light under which a coloured material is examined be composed solely of one kind of coloured rays, or what is termed a *monochromatic* light, then arises a very different state of matters. The material, no matter how brightly coloured or dyed it may be in daylight, will reflect only that single colour, or none at all. Red, yellow and blue colours, when examined under a ruby lamp, will be found to lose their bright variety of hue. The red will appear a pale red, the yellow appears a lighter tint of red, while the blue appears a black. A simple and instructive experiment is to take a pattern sheet containing a variety of beautiful dyed colours and view it under a monochromatic yellow light, obtained by sprinkling common salt on the wick of a spirit lamp. It will be seen that, under such a light, colours cannot be distinguished from each other; reds, blues, pinks, greens, etc., all appear of the same yellowish grey, deepening into black. Such an experiment shows to us that variety of colour depends altogether upon the quality of the light which illumines, and that the wide variety of hues seen in daylight is owing to the great number of different kinds of coloured rays, of which the light itself is composed. The slight differences noticed in the appearances of dyed shades, especially the blue and violet class, when viewed under artificial lights are due to the same cause; *i.e.*, a deficiency in the light of certain blue and violet coloured rays in comparison

with sunlight. The endless number of hues present in nature arise from the different degrees and methods in which the light is affected.

§ 5. **PRODUCTION OF COLOUR.**—The colours of natural objects are produced, not by one method alone, but by several different phenomena of light. These, with the exception of *absorption*, which is of special interest to dyers and all colourists, will be but briefly noticed here; and, should the student desire further information on these beautiful and interesting phenomena, he is referred to the larger text-books on Colour.

§ 6. **Absorption.**—This is the commonest way in which colour is produced. The colours of dyes, pigments, stained glass, the innumerable tints of flowers, leaves, rocks, etc., are all examples of the selective absorption of certain coloured rays of the sunlight, with the reflection or transmission of others. For example, the blue pigment known as French ultramarine reflects to the eye nearly 40 per cent. of the green-blue, blue and blue-violet rays; while the remaining rays, consisting of red, orange and yellow, are absorbed within the pigment. Thus the blue colour of ultramarine is due to its quenching all those rays from red to yellow, and reflecting the remainder, *i.e.*, from green to violet, which combine, within the eye, to give the sensation of an ultramarine blue colour.

Another simple example may be seen in the brilliant pigment, emerald green. This colour is found to reflect to the eye nearly 70 per cent. of the pure yellow-green, green and blue-green rays of the spectrum, and 25 per cent. of the blue and violet; while the red, orange red and orange are completely extinguished.

Likewise the brilliant red colour known as vermilion absorbs all the violet, blue, green-blue and green rays, leaving only the yellow, orange and red rays to be reflected. The

light reflected from vermilion consists of 90 per cent. of the orange and red rays, hence its characteristic *scarlet-red* colour. As this phenomenon of absorption of certain rays, with the reflection of the others, produces the innumerable shades commonly found in nature, and gives to the artist and the dyer their many varieties of colour, it is by far the most important of all colour phenomena to the colour mixer, and will accordingly be treated specially in a subsequent chapter.

§ 7. **Diffraction, or Interference.** — This phenomenon, which depends upon the behaviour, or what is termed the *interference*, of the waves of light, under special circumstances, gives rise to the most beautiful display of colours. The gorgeous hues of the soap bubble, or tar films upon water, the feathers of the peacock, humming bird, and other foreign birds, the iridescent colours on the wings of beetles, of antique glass, mother-of-pearl, the delicate tints of the opal, etc., are all examples of "interference" or diffraction colours. The beautiful colour combinations seen by viewing crystals in polarised light are examples of the same class.

§ 8. **Dispersion.**—As this third phenomenon of light displays the most exquisite colours, it forms, like diffraction, one of the most fascinating studies for the scientific colourist. In this method of colour production the rays of sunlight undergo neither absorption nor interference, but are simply separated, or dispersed, on account of their different wave-lengths, or what is termed *refrangibility*. The beautiful band of colours known as the spectrum, obtained by passing light through a prism (see Chap. II.), the colours of the rainbow, or the sparkling dewdrop, glowing with emerald and ruby, are examples of dispersion colours.

§ 9. **Fluorescence.** — Certain substances and liquids, when illuminated with daylight, emit a peculiarly coloured light, which is termed fluorescence. A piece of uranium

glass and a solution of sulphate of quinine give respectively a bluish-green and a purplish-blue fluorescent light. Crystals of anthracene show a beautiful violet fluorescence, while some of the coal tar colours, such as the eosines, rhodamine, etc., "fluoresce" an orange or reddish hue. The bluish "bloom" seen on mineral oils is also due to the same phenomenon. Resorcine blue and uranin yellow—both aniline colours—are splendid examples of fluorescent substances. An alcoholic solution of chlorophyll, or the green of leaves and plants, shows a claret-red fluorescence. This phenomenon is closely related to that of *phosphorescence.*

§ 10. **COLOURS OF OPAQUE BODIES.**—An opaque body which reflects to the eye from its irregular surface all the rays of incident light in equal proportion, will appear of the same colour as the light which illumines it. Thus a piece of chalk or white paper is white in daylight, yellowish in a yellow artificial light, red in a red light, or green in a green-coloured light. But, in most cases, objects absorb within themselves certain of the rays of light, and reflect the remainder, which combine together, as they enter the eye, to produce what we know as the colour of the object. Vermilion and aniline scarlet, for example, quench or absorb all the coloured rays of the spectrum, except those of the red and orange red, which are reflected, and these rays give to them their characteristic red colour. If, however, a piece of cloth dyed scarlet, or an object painted with vermilion, be illumined with a green or a blue light, they fail to reflect any of these blue or green coloured rays, and consequently they appear *black.* This partly explains the reason why red objects, such as a stick of red sealing-wax, a scarlet poppy, or a soldier's red tunic appear black when seen late in the evening when the sun has set, or in the dusk when the daylight is of a very blue quality.

Objects which absorb to themselves all the rays of light

and reflect none to the eye are therefore devoid of all light or colour and appear *black;* and the state where an equal proportion of rays is absorbed, and the other reflected is termed *grey;* being intermediate between white and black.

§ 11. **BODY COLOUR.**—If the light penetrates for a short distance into the substance, and is then reflected out again, it will generally appear coloured if any selective absorption takes place within the body of the substance. That is, if any of the light rays are absorbed during their passage, the substance will appear coloured by the light which is reflected.

§ 12. **Colour of Transparent Bodies.**—If a transparent substance absorbs certain coloured rays, and transmits others, it will appear coloured from the combination of the transmitted rays.

§ 13. **Surface Colour.**—Other substances reflect certain rays from their surfaces and transmit the remaining rays. Thus, for example, gold reflects from its surface the orange and yellow rays which give to it the characteristic golden colour; but, if gold be made sufficiently thin—as in gold leaf —to become transparent, it will be found to transmit the blue and green rays. This phenomenon of *surface* colour, or what is sometimes termed *metallic reflection*, may be observed in many of the coal tar colours, such as magenta crystals, eosine, methyl violet, some aniline greens, blues, and others. Colours of such a nature appear of a different hue according as they are viewed by transmitted or reflected light. Indigo powder, for example, is a blue colour, yet when it is pressed so as to show a polished surface, or when it is crystallised, it gives a coppery reflection. The crystals of magenta show a dark green reflex like the wings of certain beetles; while they transmit when dissolved a beautiful magenta-red colour. Methyl violet reflects a clear, greenish-yellow light. Many aniline greens and blues, such as malachite or benzaldehyde

green, victoria green, china green, aniline blue, alkali blue, etc., show a coppery red or a brownish metallic lustre. Although dyers and colourists soon get accustomed to these phenomena, it is nevertheless remarkable that a green crystal should give a *red* solution, and a greenish-yellow substance give a *beautiful violet.* These facts seldom fail to arouse astonishment among those who see the aniline dyes dissolved for the first time. This reflex depends greatly upon the chemical constitution of the colour salt ; thus, with the malachite green group the crystallised oxalate salts show a golden yellow, a yellow green, or a green lustre, while the zinc double salts of the same bases show generally a coppery or a red-brown reflex. Metallic reflection colours may be readily seen by making a strong alcoholic solution of these dyes, and allowing a few drops to evaporate on a glass plate. Their reflected and transmitted colours can thus be readily examined. Generally, the colour of the light *transmitted* and of the light *reflected* are complementary to each other, *i.e.*, if the two coloured lights were combined they would again form white light.

CHAPTER II.

ANALYSIS OF LIGHT—SPECTRUM—HOMOGENEOUS COLOURS—READY METHOD OF OBTAINING A SPECTRUM—SIMPLE ABSORPTION SPECTRA—AID OF SPECTROSCOPE.

§ 14. If a ray of ordinary sunlight be passed through a wedge-shaped piece of glass called a prism, the path of the light will be bent or *refracted*, and at the same time the light will be separated or dispersed into a series of the most beautiful colours. This series of colours is called the *spectrum*, a word which simply means an image or likeness (Latin *spectrum*, an image). When carefully examined the solar spectrum is found to consist of six well-known colours—red, orange, yellow, green, blue, violet. This experiment was first made by Sir Isaac Newton in 1665, who thoroughly investigated the complex nature of light; but, nearly 150 years previous to this, the astronomer Kepler had first demonstrated its compound nature. We have already seen (§ 2) that the longest visible light waves produce the sensation of red; while the shortest or more rapid vibrations produce to our eye the sensation we call violet, and between these two extremes are a vast number of intermediate wave-lengths all merging into one another. Thus between the extreme red and the yellow we find many gradual steps, representing bright cherry red, orange red, orange, and orange yellow. Again with a gradual diminution in wave-length the yellow merges into yellow green, then into a pure green, and from

green, by a great number of insensible gradations, the light changes to blue, violet blue, and finally to violet. White light, therefore, is composed of a great number of differently coloured rays, distinguishable from one another by the rapidity of their vibrations, or, in other words, by the length of their waves. With the aid of the prism these rays of light

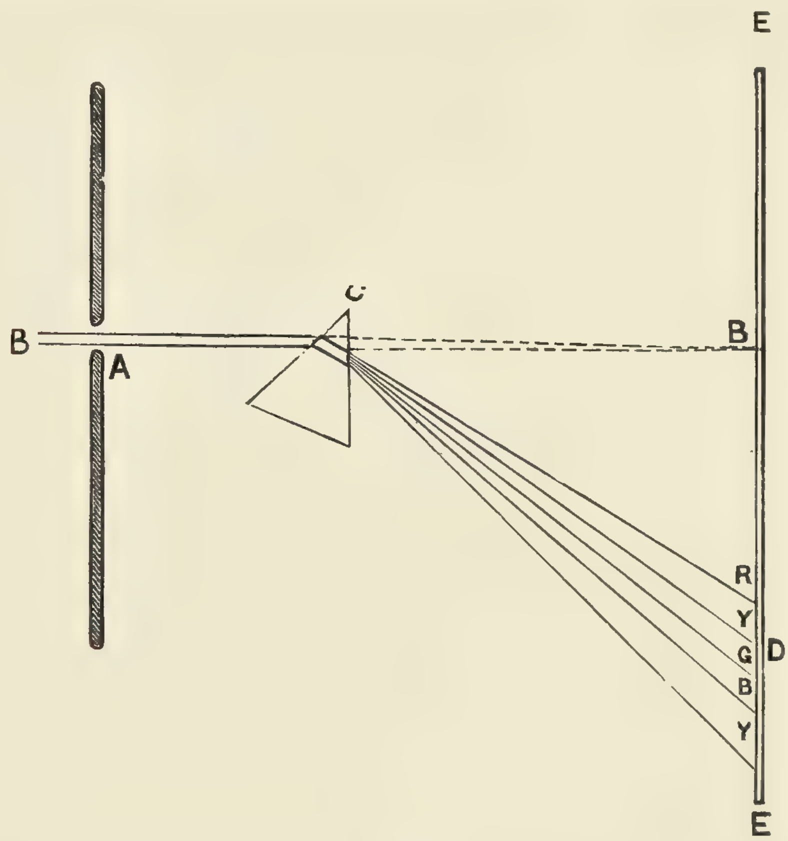


FIG. 1.—Showing refraction of light and production of spectrum by means of the prism.

of different wave-lengths are separated or "dispersed," and spread out in the spectrum in a beautiful series of colours, all arranged according to their respective wave-lengths. The following illustration (Fig. 1) shows how, with an inexpensive glass prism, we might perform this famous experiment of Newton's for ourselves. (A) represents a slit whereby the light is admitted into a dark room. The beam of light

(B) in passing through the glass prism (C) is bent or refracted out of its course, and in being so, is analysed into its various component rays which go to form the spectrum (D), which can be received on a white screen (E). If we begin at the top of the spectrum nearest the spot B, which represents the direction the beam of light would have taken had it not been refracted by the prism, we find that the first colour is red, then orange, yellow, green, blue, while the light most refracted is violet.

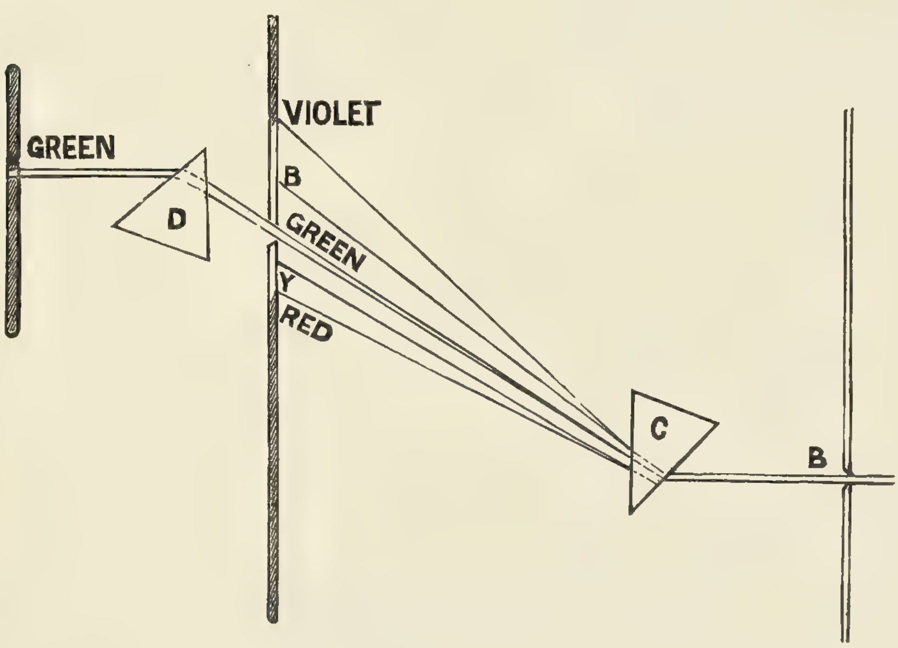


Fig. 2.—Showing homogeneous nature of spectrum colours: green not further decomposed.

§ 15. What is termed the *refrangibility* of a colour (*re*, again, and *frango*, I break in pieces) is the extent to which the colour is refracted or bent in its passage through the prism. Hence red and orange are described as colours of "*low* refrangibility," and colours of a "*high* refrangibility," or those "belonging to the more refrangible end of the spectrum," are understood to be the blue and violet class.

§ 16. The colours of the spectrum consist of unmixed or

homogeneous lights, and they cannot be further decomposed into any other colours. Thus, for example, the green or the violet rays of the spectrum, when passed through another prism, undergo refraction as usual, but they are not decomposed into yellow and blue, or red and blue as we might have imagined; but remain the same colour, showing that they

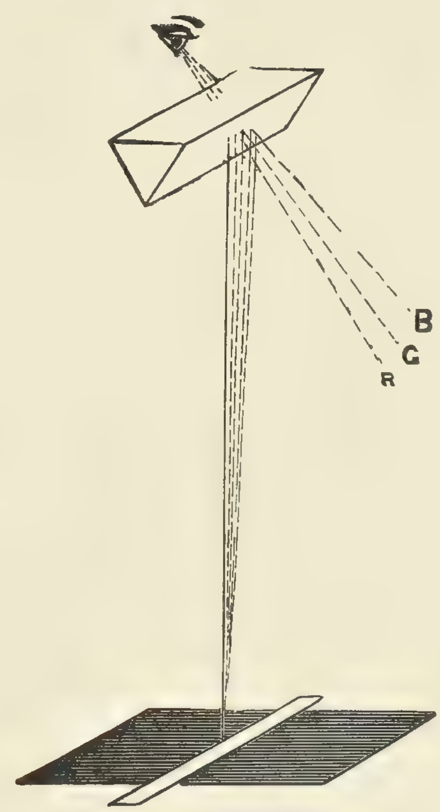


FIG. 3.—Simple method of obtaining a spectrum.

are pure and unmixed colours. The various hues seen in everyday life—the dyes and pigments and the colours of flowers, etc.—are never homogeneous, but are mixtures of various differently coloured rays. The foregoing diagram, Fig. 2, shows how the purity of spectrum colours may be shown. The spectrum is thrown upon a cardboard screen similar to that in Fig. 1 and a hole is pierced at the desired part of the spectrum—say, in the green (G)—to separate

the rays. These rays are again passed through a prism (D), when it will be observed that, though the coloured ray is refracted, no other colour is separated. But, when we come to analyse the apparently pure colours of dyes and pigments, we find that they are often very far from being pure, and contain a large number of other coloured rays. No dye or coloured pigment is known to be absolutely homogeneous in its coloured light.

§ 17. The readiest method of obtaining a spectrum for studying colour is by viewing with the prism a well-illuminated strip of white paper placed on a dark ground—say, a piece of black velvet material. Fig. 3 illustrates how

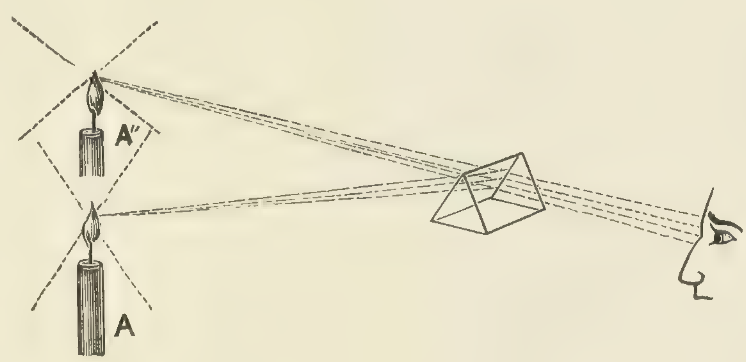


FIG. 4.—Refraction of light.

this is best arranged. The refracting angle of the prism should always be held parallel to the object examined. The dotted lines converging to the eye represent the direction of the rays emerging from the prism, and indicate the locality where the spectrum will appear to the observer. The white strip of paper, on viewing through the prism, will appear coloured the various colours of the spectrum—red, green, and blue. As the rays which traverse a prism are bent, or refracted, away from the refracting angle, as seen in Fig. 4, the object A when viewed through the prism will appear more in the direction of the angle than is really the case, as at A″.

In practice it is always considered best to adjust the prism so that the path of the ray of light A makes equal angles with the two sides at which refraction occurs, thus:—

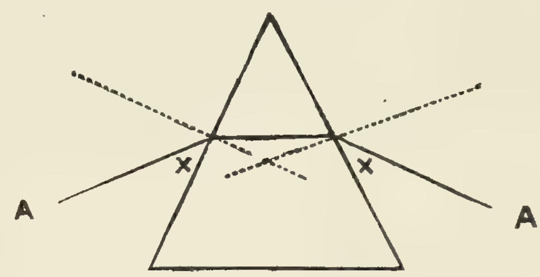


FIG. 5.—Refracting angle of prism.

§ 18. If we place a *blue* strip of paper in a line with the white one, and examine them both together in the same manner, we will find the two spectra side by side are not alike.

In the spectrum of the blue will be seen little or no red, orange and yellow rays corresponding to those present in the spectrum of white; while the green, blue and violet rays are similar to that of the white strip, and in exactly the same position. The red, orange and yellow rays have been quenched or *absorbed* by the blue colouring matter, and as only the green, blue and violet rays are reflected to the eye, the result of their combination gives the sensation of a *blue* colour. In Fig. 6 (1 and 2) we have a representation of how the spectra of white and blue differ from each other. The shaded parts in the spectrum of No. 2 (the blue) show where the coloured rays are absorbed, and the *un*shaded parts show where the colours are reflected.

Take again a strip of paper dyed *red*, and examine it with the prism in the same manner. We find that its spectrum, No. 3, is an exact contrast to that of the blue, No. 2. All the bright colours at the red end of the spectrum—*i.e.*, red, orange, yellow—are present, while the green, blue and violet rays are absent, having been absorbed by the red colouring matter. See No. 3, Fig. 6.

We have considered three simple examples of spectra, and each differing in composition. Examples 2 and 3, where certain coloured rays of the spectrum are absent or absorbed, are termed *absorption spectra*, and the study of such spectra is of invaluable assistance to the colourist in determining the optical nature of all the colours, pigments, dyes with which he works. Here, then, we have an example of a colour

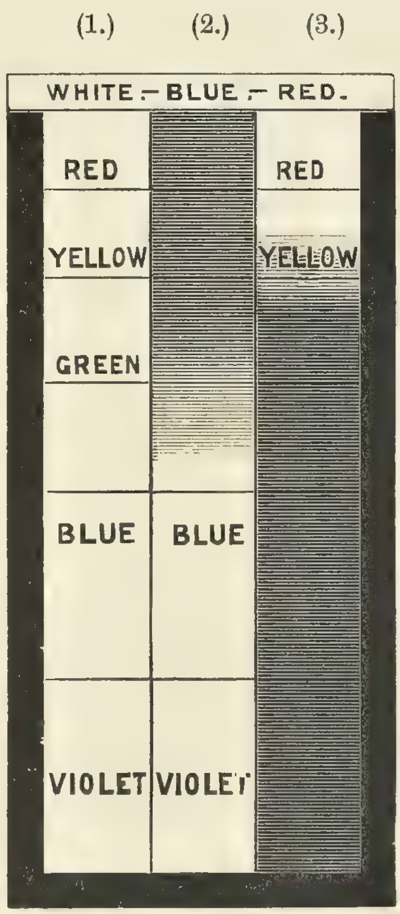


FIG. 6.—Simple absorption spectra. (1) White light. (2) Blue. (3) Red.

being produced by the quenching of certain parts of the solar spectrum, the remaining coloured rays combining together to produce the characteristic colour of the substance. These two absorption spectra are of the simplest nature possible, but the spectra of many colouring matters are often of a complex nature, as may be seen in Chapter VI. It will

be observed that the colour present in the absorption spectrum, is always in identically the same position as in the spectrum of white, but not similar in brightness to that of the spectrum of white light. If, instead of viewing red and blue, we take any other colour, such as green, yellow, violet, olive, or russet, we shall find that *absorption bands* are always present. Many coloured pigments and dyestuffs have their own peculiar and characteristic absorption spectra (see Fig. 22).

§ 19. These experiments, conducted with the assistance of the simple hand prism, are indeed most interesting and instructive, but they are very rough. It would be a difficult matter to locate with any degree of accuracy the precise spot on the spectrum where yellow merges into green, or green gradually changes into a pure blue, as all the colours of the spectrum blend beautifully into each other. It would, therefore, be a difficult and unsatisfactory task to try and separate the various colours, and to specify their exact positions on the spectrum, had there not been discovered a remarkable feature in the solar spectrum which enables us to locate with the greatest accuracy any of the colours. It is here that the valuable aid of the spectroscope comes in. In order to understand the great assistance of the spectroscope in scientific colour work, we must consider the nature of this discovery, which has already proved so valuable in other branches of science.

CHAPTER III.

EXAMINATION OF THE SOLAR SPECTRUM—DARK LINES—LOCALITY OF THE COLOURS—THE SPECTROSCOPE: ITS CONSTRUCTION—ABSORPTION SPECTRA—COLOURISTS' USE OF THE SPECTROSCOPE.

§ 20. If sunlight be admitted through an exceedingly fine slit and examined with the prism, it will be noticed that the spectrum obtained is not perfectly continuous, but is crossed by many minute parallel lines or gaps. These "dark lines" were first described by Wollaston in 1802, and in 1814 Fraunhofer, a German optician, counted as many as 600, and mapped them out in their proper positions on the spectrum chart; hence they are often termed the "Fraunhofer lines. These minute lines are *fixed*, never varying in their position; and are, therefore, of the greatest assistance to colourists when describing, with scientific accuracy, certain pure colours. As these lines are always found to occupy precisely the same places in the colours, they serve as infallible landmarks, or lines of reference, for specifying accurately any portion of the solar spectrum. To the principal fiducial lines have been given the letters of the alphabet—A, B, C, D, E, F, G and H—by which means the various colours of the spectrum may be easily identified. As these dark lines are being continually referred to in colour science, the student should note carefully, and commit to memory, their position in the spectrum. Thus, at the extreme red end of the spectrum is a strong line A (see Fig. 7). B and C are in the cherry red. D is the strong and characteristic line found in the

orange yellow. (With a powerful spectroscope the D line is seen to consist of two lines close together.) The two promi-

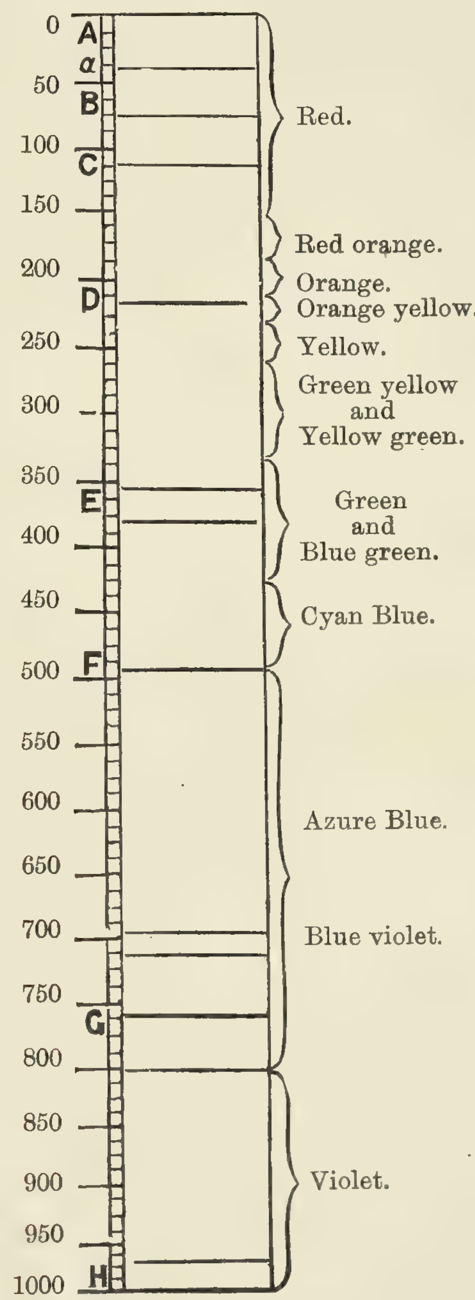


FIG. 7.—Solar spectrum, showing principal dark lines and the locality of the fundamental colours.

nent lines in bright green are the E lines, F is in the green blue, G is in violet blue, while the two lines H are in the extreme violet. Between these principal and outstanding

lines are a great number of others, of less importance to the colourist. Fig. 7 represents the solar spectrum with the relative positions of its characteristic fixed lines.

§ 21. According to Professor Rood, of Columbia College, who has made elaborate investigations on this subject, 1,000 parts of ordinary white sunlight are composed of differently coloured rays in the following proportions :—

Red	54	Yellow green	121
Orange red	140	Green and Blue green	134
Orange	80	Cyan Blue	32
Orange yellow	114	Blue	20
Yellow	54	Blue violet	20
Greenish yellow	206	Violet	5
			1,000

The same investigator, by dividing the solar spectrum into 1,000 divisions between lines A and H, thus locates the positions of the principal fixed lines (see scale down spectrum in Fig. 7) :—

A	0	E	363·11
B	74·02	F	493·22
C	112·71	G	753·58
D	220·31	H	1,000

§ 22. The spectra given by other sources of light, such as the electric arc, oil lamp or coal gas, are all continuous : that is, they do not show the presence of any dark lines, and differ therefore from the spectrum of sunlight. The existence of these lines is caused by the absorption of the light in passing through the glowing vapour of metals and other bodies present in the sun's atmosphere ; each substance in the state of a vapour having the remarkable power of absorbing, or of being opaque to, the same kind of rays as it emits. After long and laborious research, Fraunhofer, Kirchhoff, Bunsen and others, established the law that *every substance which emits at a given temperature rays of certain*

orders of refrangibility, possesses the power, at that same temperature, of absorbing rays of those same orders of refrangibility.

§ 23. **THE SPECTROSCOPE: Its Construction.**—Before proceeding to study the science which underlies the art of colour mixing, it may be well to devote a little attention to the construction of the spectroscope; an instrument which has now become invaluable in the hands of the scientific colour mixer for determining the true interpretation of colour mixing phenomena. As the naked eye is unable to *analyse* light, or to distinguish the differently coloured rays

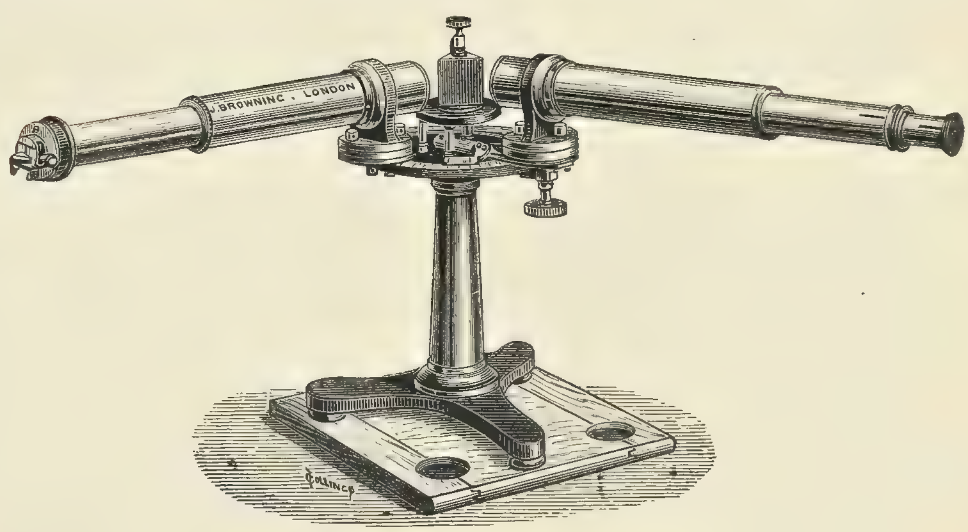


Fig. 8.—One prism spectroscope.

emitted by a coloured object, it is necessary to enlist the aid of the prism in all experiments where the component rays of a colour have to be separated. A convenient form of apparatus for this purpose is found in the spectroscope, a word which means literally an instrument for *viewing an image* (Lat. *spectrum*, an image, and Gr. *skopeo*, I view). It consists of one or more prisms so arranged that the spectrum instead of being thrown upon a screen, can be examined directly through a telescope. To the scientific colourist the spectroscope is invaluable, as by its aid the various differently coloured rays constituting a colour are separated or analysed,

and the true nature of any coloured light—whether homogeneous or mixed—can be accurately determined. In our illustration (Fig. 8) we have a simple form of spectroscope by Browning with one prism, and Fig. 9 with two prisms. The instrument is firmly fixed upon an iron stand. The coloured light to be examined enters by the tube having an extremely fine slit made by two knife edges (see left of illustration), the width of the slit being easily regulated by means of a screw. After passing through this very fine slit the light

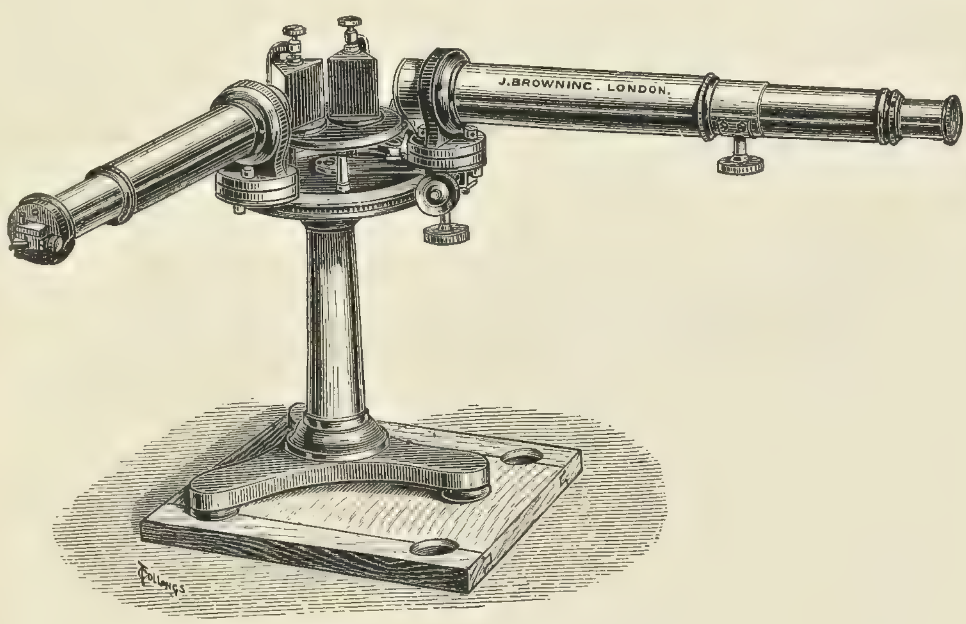


FIG. 9.—Two prism spectroscope.

is made to pass through a convex or collimator lens, whereby the rays of light are made parallel before entering the prism. By this arrangement a purer spectrum is obtained. The light, having been refracted and decomposed in passing through the prism or prisms, is made to enter the second tube, which consists of a telescope; and the image of the spectrum is magnified before it reaches the eye. The telescope tube is so made as to be movable round a graduated circle which enables the observer to adjust the instrument to any part of the spectrum desired. A finely graduated

scale or vernier (which can be seen in Fig. 8) is employed for purposes of measurement, or for locating with accuracy the position of the dark lines in that part of the spectrum under special examination. Most spectroscopes have also fixed to the slit a simple reflecting prism for allowing two spectra to be examined side by side simultaneously.

This little device is useful where two different absorption spectra are to be carefully compared with each other, or where the spectrum of white light is wanted for comparison. For colour chemists a most useful form of spectroscope is that known as the compound, direct vision instrument (seen in Fig. 10), having several prisms composed of crown glass and flint glass arranged alternately. This form of spectro-

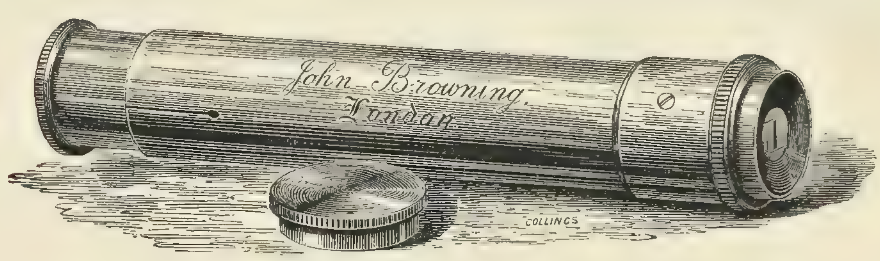


FIG. 10.—Direct vision spectroscope.

scope, made also by Browning of London, gives wonderful results, considering its small size.

The compound prism is placed inside the brass tube, at one end of which is the slit for admitting the light. This can be widened or narrowed at pleasure by turning round the ring with the milled edge, seen at the slit end of the spectroscope (see right of illustration). This little instrument, though readily carried in the waist pocket, gives excellent results. It shows the principal dark lines of the spectrum, as seen in Fig. 7, and reveals to the colour chemist the characteristic nature of the absorption bands of the dyed materials, colours, or dye solutions under examination.

§ 24. **Use of the Spectroscope in Colour Examinations.**—Though the spectroscope has now become of much value

in many branches of scientific research, its employment in the domain of colour chemistry is, to a certain extent, more limited. Some dyestuffs and colouring matters, having totally different chemical constitutions, may yet show similar *absorption spectra* on their examination with the spectroscope. Before proceeding, it may be well to explain more fully the term *absorption spectrum*, which will be used frequently during our study of colour mixing phenomena.

§ 25. We have already learned that all solid bodies, when heated to a white heat, give a *continuous* spectrum; that is, one which is not broken by any minute dark lines or bands like that in the sun's spectrum. The light from the electric arc, an oil lamp, ordinary coal gas, acetylene gas, or from a candle are all examples of illuminants giving a continuous spectrum. If a glass beaker containing a dilute solution of the yellow dye picric acid (*trinitro phenol*) be placed between any of these flames, giving an unbroken spectrum, and the slit of the spectroscope, it will be found that the light transmitted through the yellow dye has undergone a change. While all the rays of the spectrum, stretching from the red to the green, are freely transmitted, the blue and violet end of the spectrum is absent,—a total extinction of these coloured rays having taken place. The result is an incomplete or *absorption* spectrum; certain of the coloured rays having become *absorbed* in the passage of the light through the yellow solution. The *locality* of absorption is described by means of the fixed dark lines of the spectrum, which, in this case, starts between the lines F and G in the blue, and continues all the length of the spectrum to the H line in extreme violet. A simple way of representing the absorption spectrum of a yellow dye would therefore be as represented in Fig. 11 (A); the shaded portion of the spectrum shows where the colours are absorbed or absent. Such an experiment also shows that a yellow dye does not appear yellow

simply because it transmits the yellow rays of the spectrum, but because it absorbs that part of the spectrum complementary to yellow, *i.e.*, blue and violet. The red, green and blue-green rays, which are not absorbed, are combined on the retina of the eye, and produce *white* light; thus the yellow colour of the picric acid, naphthol yellow or of any other yellow dye, is not a pure or monochromatic colour, but consists of yellow mixed with a large proportion of white light.

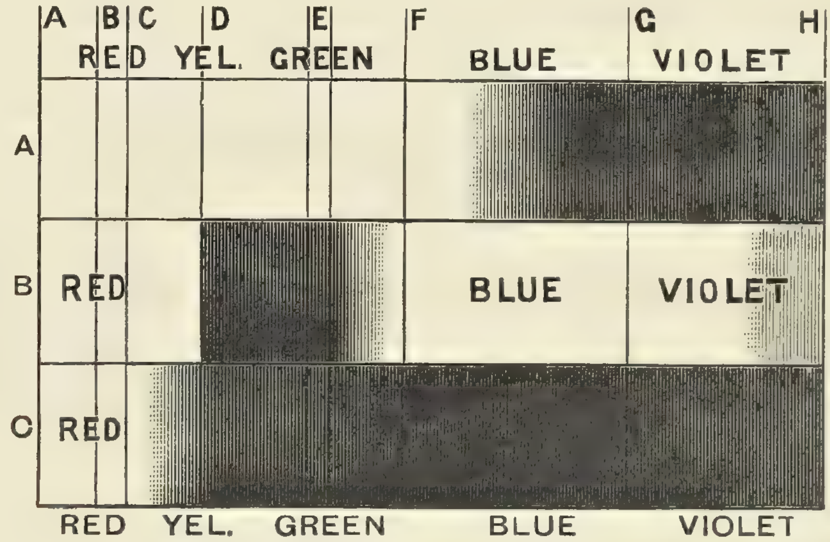


FIG. 11.

A = Representing the absorption spectrum of picric acid.
B = Magenta (dilute).
C = Magenta (strong).

Another simple example of an absorption spectrum will be found by viewing with the spectroscope a dilute solution of the beautiful pink dye, magenta. In this case the greenish-yellow and green rays are absorbed, making a dark break or absorption *band* from the line D in yellow to nearly line F in the blue green (see Fig. 11, B). In dilute solution the blue and violet are transmitted, with slight absorption; but, if the solution be strengthened, all the coloured rays are completely absorbed, leaving only the red to be transmitted. This explains the bluish-pink hue of a dilute magenta solution,

and the pure cherry red of a more concentrated solution (see Dichroism, § 39). The absorption spectra of magenta *dilute* and *strong* may be represented as in Fig. 11, B and C.

For other examples of colouring matters showing decided and characteristic absorption bands see Chapters IV. and VI.

§ 26. Dyed fabrics, pigments, stained glass, and indeed all coloured materials, can be examined in the same manner with the spectroscope. In all cases an absorption spectrum is obtained; but that given by solutions, where the light is transmitted through the liquid, is purer than what can be obtained by viewing the reflected light from dyed or coloured surfaces. Reflected coloured light contains a certain admixture of white light (reflected unchanged from the surface of the material), which tends to impair the sharpness of outline in absorption spectra.

The prism of the spectroscope analyses the coloured light into its constituent rays, and in colour chemistry there are many instances where spectroscopic examination is of the greatest importance. This is particularly so when certain colouring matters show decided and easily recognisable absorption bands on the addition of different chemical reagents. Thus the spectrum of the well-known colouring matter alizarin, or madder, is unmistakable when examined first in aqueous solution, then with the addition of a few drops of ammonia. Its alcoholic ammoniacal solution also gives a characteristic absorption spectrum. The spectra of chlorophyll (the green colouring matter of leaves and plants) of red blood, of acid extract of indigo, methyl violet, eosine, magenta, of litmus in acid and alkaline solution, and many others are of much interest. Solutions of the aniline dyes will be found interesting and instructive subjects for study with the spectroscope, as they possess sharp and decisive absorption bands.

§ 27. In studying the various phenomena of colour mixing the analysing power of the prism is of great service, as it not only reveals the true nature of the coloured light, but also the cause of many unexpected modifications in hue which some colours undergo when viewed in artificial light.

Two pieces of dyed material may match each other closely in colour when examined in good daylight, and yet present a considerable difference in appearance when viewed in a yellow illuminant like ordinary coal gas, or candlelight. Every practical dyer and colourist could give many instances from his own experience. This difference in behaviour between two colours apparently identical is due to the fact that colours, similar to the naked eye, may have a different optical composition, or be produced by the combination of different parts of the spectrum. As the naked eye is unable to separate the various coloured rays constituting a mixed colour, it cannot, therefore, tell a pure or homogeneous colour from a compound one: two shades may appear identical to the unaided vision, and yet be composed differently and have different absorption bands in their spectra. For example, the eye cannot distinguish the difference between ordinary white light composed of all the colours of the spectrum and the white light, produced by combining green and purple or red and blue-green lights together. The prism, or spectroscope, would at once reveal the difference. Dyed materials often show unexpected appearances when viewed in gaslight, and in such cases the spectroscope is of much service to the colour chemist and dyer in enabling him to discover the cause of such modifications. In colour mixing and dyeing it will be found that a knowledge of the optical properties of the dyestuffs employed is of some little service in producing the desired shades. It is, indeed, one of the first duties of the colourist to examine what is termed the "mixing

qualities" of the various colouring matters placed before him; and to determine their capabilities of producing good, useful shades by admixture with others. By viewing with the pocket spectroscope samples dyed with any colouring matter, he can tell whether the colour can be employed for producing certain desired effects. Blues for example, which show a ready transmission of the red rays, cannot be employed in making a pure and brilliant green by admixture with yellow. Reds which transmit a certain amount of the blue rays are found to become bluish when diluted or reduced to produce tints and cannot be used for making pure scarlets. By carefully examining the absorption spectrum of a dyestuff, any little optical peculiarities can be readily detected which would otherwise pass unnoticed until the colours were mixed or dyed. This explains why colours when mixed with others, often do not give the results expected by the dyer. Thus a little previous spectroscopic examination might save the colour mixer some trouble.

The small direct vision instrument, already referred to at Fig. 10, is most convenient for such work. Dye solutions give much more decided and characteristic absorption spectra than the same dyestuffs when dyed or printed or any material, either wool, silk, or cotton; as a quantity of white light is reflected from the surface of the fabric, which tends to dilute, and render less decisive, the absorption spectra of the dyes. The positions of the absorption bands of the dye solution and of the dyed material are generally identical; except when the property of dichroism (see § 39) is present to any great extent in the dye solution.

CHAPTER IV.

COLOUR BY ABSORPTION.

ABSORPTION OF COLOUR PRODUCED BY ADMIXTURE—ABSORPTION SPECTRA—SOLUTIONS AND DYED FABRICS—LUMINOSITY CURVES—ABSORPTION CURVES—DICHROISM—DICHROIC COLOURED FABRICS IN GASLIGHT.

§ 28. Though the exquisite hues produced by the interference and dispersion of light are of great interest to the philsopher, they do not play so important a part in our everyday life as the colours produced by *absorption.* It is owing to this phenomenon that all the common objects of nature owe their colour. The green of the grass, the changing hues of spring, summer and autumn foliage, the blueness of the sea, the glorious variety of colour displayed in flowers, the colours of the artist, the glass stainer, the calico printer and dyer, are all due to absorption.

When two coloured solutions are mixed together, or two differently coloured glasses viewed through each other, the resulting colour obtained is that which is transmitted by both colours in common. Thus, when yellow and blue dyes are mixed, or when a yellow slip of glass is viewed through a blue one, a green is produced. The true interpretation of this simple experiment is readily found by examining these two colours with the prism or spectroscope. The green colour is produced, not simply because the yellow transmits only the yellow rays and the blue only the blue rays, but because green is the only colour common to them both, all the others being more or less absorbed or quenched. All yellow pig-

ments and dyes are found to consist not only of yellow, but red, orange, and green rays (see A, Fig. 11). As already observed in § 25, all ordinary colours (except the pure spectrum colours) are heterogeneous, *i.e.*, they reflect to the eye many differently coloured rays, which, however, cannot be distinguished or separated by the naked eye. Blues are likewise found to reflect not blue rays only but varying proportions of green, violet, and a little red light. When two such colours as the yellow and blue are combined together it will

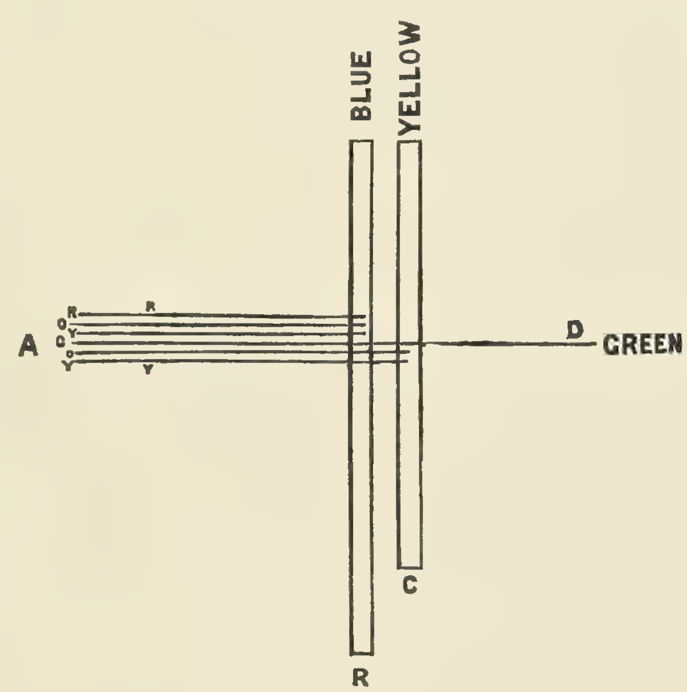


FIG. 12.—Showing production of green by combining blue and yellow glasses.

be found that *green* is the only colour common to both of them, and is therefore freely transmitted; the others being more or less absorbed. This, then, explains why a green is produced by the combination of yellow and blue.

§ 29. This may be more readily explained by the aid of the following diagram (Fig. 12), which represents a ray of ordinary white light (A) composed of its red, orange, yellow, green, blue and violet colours passing through a sheet of blue glass

(B) and a sheet of yellow glass (C). The light (A) in passing through the blue glass, loses three of its constituent rays, those of red, orange, and yellow, which are absorbed or quenched, and are therefore not transmitted; while the green, blue, and violet rays are allowed to pass freely through. These, on entering the yellow glass, are not all transmitted. As yellow does not transmit or reflect any blue or violet light, these coloured rays are caught and absorbed, leaving only the green to pass through alone. Hence the white light, which was composed of six differently coloured rays, has only the green rays left unabsorbed (see D in Fig. 12). Such is

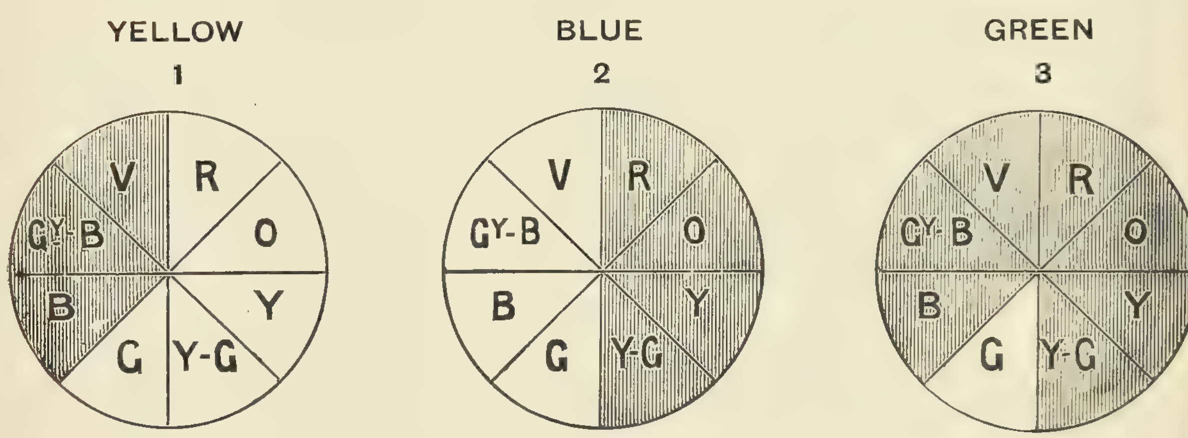


FIG. 13.—Chromatic circle, showing production of green by the admixture of yellow and blue.

the true interpretation of this common phenomenon. If a pure or homogeneous blue and yellow could be obtained the result on admixture would not be a green, but probably a pinkish grey; as the combination of blue and yellow *lights* produces a purplish white (see Fig. 3, plate iii.).

The effects of colour absorption by admixture or combination may be illustrated in a very simple manner by employing a chromatic circle. The circle in our illustration (Fig. 13) is divided into eight parts, representing roughly the various coloured rays constituting white light, *i.e.*, red, orange, yellow, yellow-green, blue, cyan-blue, and violet.

These are designated by their initial letters. By using shading lines to represent where absorption of colour takes place, we may show that the colour produced by admixture is the sum of the unabsorbed colour rays; or, in other words, these rays which are common to both colour constituents. Thus, in No. 1, Fig. 13, yellow reflects from red to green, and absorbs blue, cyan blue, and violet. Blue No. 2 reflects from green to violet, and absorbs all the other colours. If these two discs be placed one upon another as at 3, it will be observed that green is the only colour common to both, and is therefore freely transmitted.

This characteristic example of colour absorption may be illustrated in another way by means of the *absorption* spectra of the component colours. It is well known that picric acid or naphthol yellow and indigo extract produce a fairly good green when dyed together. This, as we have already learned, is not because the indigo reflects, or allows to be transmitted, only the blue rays, and the yellow only the yellow rays, but because, when both of them are combined, the green is the only colour which is freely transmitted by both of them. Fig. 14 is a representation of the two absorption spectra (A and B). A represents naphthol yellow, and B the indigo extract, while C shows the combination of the two. The lines A, B, C, etc., represent the fixed or Fraunhofer lines of the solar spectrum—the invaluable landmarks to the colourist (see § 20).

Spectrum A represents that of naphthol yellow, showing that this dye absorbs the violet, blue, and blue green end of the spectrum, which is shown in shade (denoting absence of colour or absorption), while the remaining colours of the spectrum—green, yellow and red—are freely transmitted.

B may be taken to represent the absorption spectrum of acid indigo extract, which shows strong absorption from the red, near the line B, through the orange, yellow, and yellow

green to the green at the lines E; while the extreme red, the green blue, and violet are freely transmitted.

When these two spectra are combined, as represented in C, we find that only the extreme red, the green, and the blue green are transmitted, which constitutes the green colour obtained by combining naphthol yellow and acid indigo extract. Such a green as the above cannot be of a perfectly pure bright hue from the quantity of red light it reflects; but, if instead of indigo blue, a purer aniline blue or a

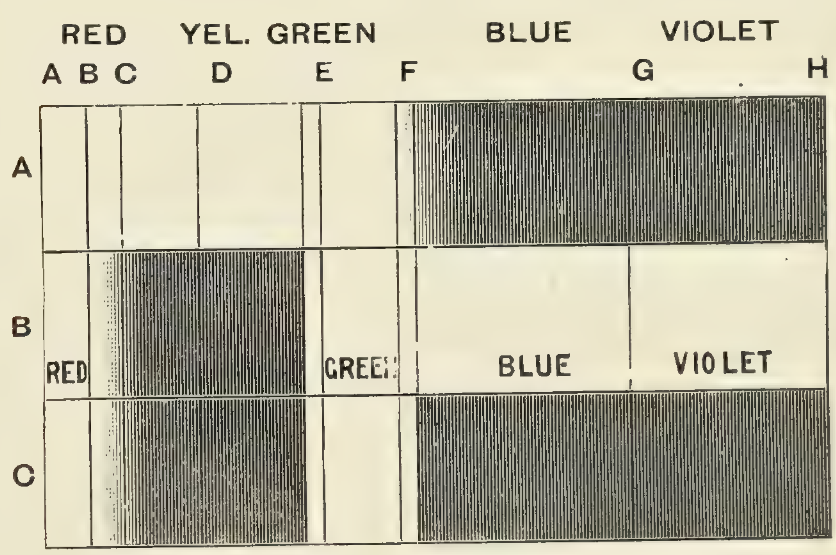


FIG. 14.—Green produced by admixture of yellow and blue, *i.e.*, naphthol yellow and indigo extract.

greenish blue be taken, which reflects little red light, then a purer and brighter green will be the result.

§ 30. When there is absorption of coloured rays by the admixture of two colours, there is produced a corresponding loss of light, or a darkness in the colour. This explains the dull appearance, or what is termed the "sadness" of all mixed shades. The more different colours there are present in a mixture, the darker, or more approaching to grey, is the result. It has been well said that "every admixture of colour is a step towards darkness". Two colours, which cut off between them all the coloured rays of light, when

combined, either on the palette or in the dye-bath, produce an extinction of light, or in other words, a black (see Fig. 15).

§ 31. In dyeing, it is seldom that two complementary dyestuffs can be found to fulfil the exact requirements in this respect, as all of them, more or less, transmit some rays in common; but by employing three dyestuffs a good pure black can be obtained. A mixture of red and a blue green, such as azo rubine and acid green, if sufficiently strong will dye a black. This may be seen on Pattern Plate No. I. at the end of the book. 1 is Victoria rubine,

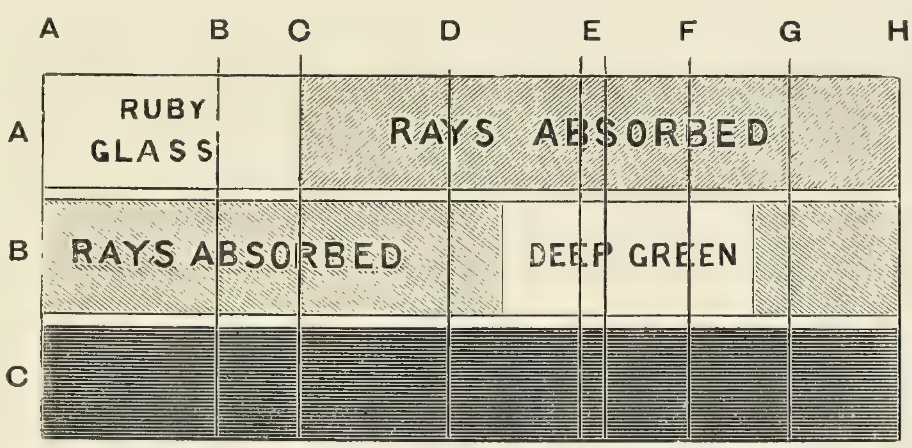


FIG. 15.—Total absorption or blackness produced by combination of red and green glasses.

2 is acid green, while 3 is a good black, dyed by combining them both together. All the rays transmitted by the one are absorbed or quenched by the other. Another good example of this total extinction of light by two coloured bodies may be found by viewing through a piece ruby glass and signal green glass superimposed. If these two coloured glasses be held up to the light, it will be found impossible to look through them when combined; total darkness being produced. This may be readily explained by the help of Fig. 15. Spectrum A represents that of the ruby glass, showing the transmission of onlv the red and orange-red rays from A

to C; the other rays of the spectrum being absorbed, are shown by shading in the diagram. This may also be taken to represent the absorption spectrum of Victoria rubine (see No. I. Pattern Plate at end). B represents the absorption spectrum of the green glass, known as "signal" green, which, as seen from its spectrum, transmits only the yellow green, green (lines E), blue green and blue (line F), while the remaining parts of the spectrum, from red to yellow green, and from blue to violet, are all completely quenched. This absorption spectrum of "signal green" glass may be taken also to represent that of acid green, which it closely resembles in colour (see No. II. Pattern Plate at end). Thus it is readily seen that if two such colours are combined, they have no coloured rays in common; no ray of light can pass unabsorbed through both. The result is that total darkness, or a black, is produced, as represented at C. The same results can be got in dyeing by combining roccelline or fast red with some of the aniline greens. By the suitable combination of three dyestuffs, *i.e.*, Victoria yellow, indigo blue and azo acid magenta, beautiful shades of grey are obtained (see the dyed specimens, Nos. 7, 8, 9, at end of the book).

The fact of colours combining to form grey or black is largely taken advantage of in dyeing and textile printing for producing soft or sad tertiary shades, *i.e.*, colours darkened with a certain proportion of grey. Complementary dyes and pigments, when combined, form grey or black; while complementary *lights*, when combined, go to produce *white* (see Chap. V.).

§ 32. The behaviour of dyestuffs in dyeing the various textile fibres is similar to that of the coloured glasses and liquids we have just studied. The fibres are dyed through to the inside, and being in themselves translucent, the light enters to a certain depth within the fibre, when it is again re-

flected. During its passage through the dyed fibre or fabric, certain coloured rays have been absorbed, and the reflected light enters the eye deprived of some of its constituent rays. In this way the colours dyed on fibres are similar to those obtained from the solutions of the dyestuffs. There is, however, one great difference between a dyed fabric and a dye solution. The light transmitted through a coloured solution is richer, and more saturated, than the same colour dyed on a fabric; owing to the fact that a certain amount of unchanged white light is reflected from the surface of the fabric by each individual surface of its fibres, thus giving to the dyed colour a paler and less rich appearance. The reflective power, or the *lustre* of a fibre, is, therefore, a most important feature in the question of dyeing. If we examine the fibres of silk and wool together, we find that silk has a much greater lustre than wool, *i.e.*, that it reflects to the eye, when held in a certain direction, a larger quantity of white light from its surface; while, on the other hand, when held in another position, little or no surface light is reflected. Thus the coloured light reflected from dyed silk may be much lighter in tint, or it may be much deeper and richer in hue than that of wool dyed with the same dyestuff. Lustrous fibres, like silk, china grass, alpaca, and some of the high lustred wools, can show, according to their position, rich full colours, almost free from any admixture of white light; or they may reflect, in unfavourable positions, a great deal of white surface light, producing a paler tint of colour. It is this sheen, or surface reflection of highly lustrous fibres, that gives to their dyed woven fabrics the beauty and sparkle; making the lustreless fibres like linen, cotton, or the poorer wools, comparatively dull and wanting in vigour. If cotton be compared with wool in the same way, it will be observed that wool surpasses cotton in lustre, the latter appearing a dead, sheenless white. It follows therefore that the colours

dyed on wool appear richer than on cotton. This is found to be so in practice, as it is most difficult to match accurately shades dyed on cotton with those dyed on wool, silk, or the finer qualities of jute. A lustreless fibre like cotton scatters its surface light in all directions, giving to the colours dyed on it a somewhat opaque, painted-like appearance, when compared with those dyed on wool. The lustre of the fibre is a most important question to the dyer, the textile colourist

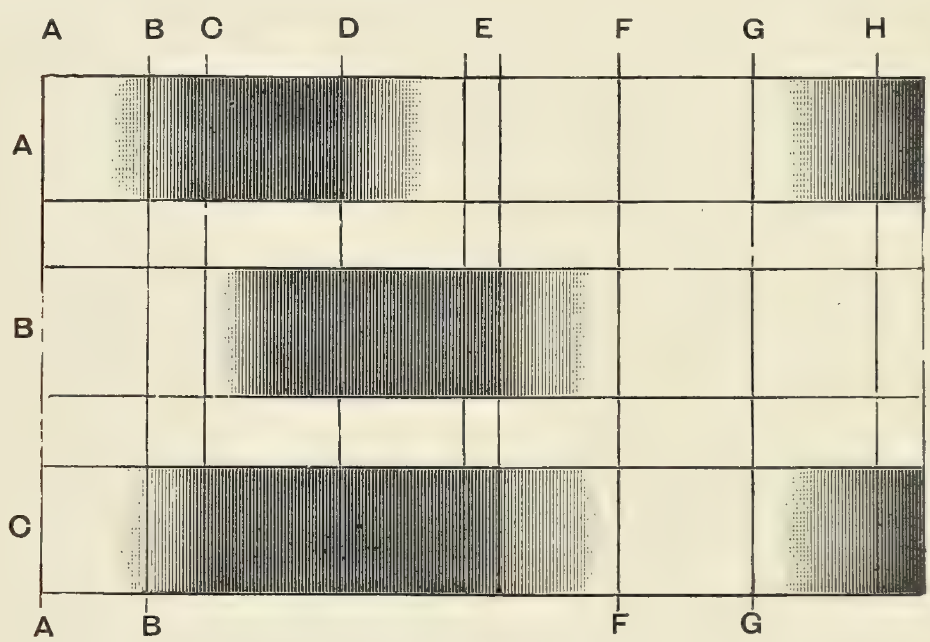


FIG. 16.—Showing production of a blue by admixture of green and violet.
A. Absorption spectrum of malachite green.
B. ,, ,, methyl violet.
C. ,, ,, blue obtained by their combination.
For dyed pattern see Plate II. at end of book.

and the colour matcher, and we shall have occasion to speak of it more fully when dealing with some of the difficulties of colour matching, in a companion volume on *Colour Matching on Textiles.*

§ 33. Another instructive example of colour absorption may be seen in the blue colour obtained by mixing together green and violet (see Fig. 16). A fairly good blue may be dyed on wool or silk by using an aniline green, such as

malachite, or china green, along with a suitable proportion of methyl violet. A light sky blue dyed in this manner may be seen at Pattern Plate II., No. 4, at end of book. Such a blue is indeed sometimes sold under the name of "indigo substitute". The formation of this blue colour may be understood after a spectroscopic examination of these two colouring matters. Greens transmit or reflect not only the green rays but a considerable portion of the blue and a little of the violet; while violets like methyl violet 3 B. reflect, along with the violet rays of the spectrum, a large quantity of blue and also red rays. When two such colours as the green and the violet are combined, it will be found that the blue rays are the only ones freely transmitted, being common to both colours. The green absorbs the red and most of the violet, while the violet absorbs the orange, yellow, and yellow green, leaving blue rays to predominate. This gives to the mixture its blue colour. A clearer idea may be obtained by studying the representations of their absorption spectra.

A represents the absorption spectrum of an aniline such as malachite, or Victoria green. The absorption continues strong from line B in the red to D in the yellow. The extreme red is transmitted along with the green, blue-green and blue rays extending from E to G, while the violet (at H lines) is absorbed.

B represents the absorption spectrum of methyl violet, showing the free transmission of the red part of the spectrum, and likewise the bluish green, blue and violet; while the orange yellow and yellow-green and green, extending from C to nearly E$\frac{1}{2}$ F, are absorbed.

C represents the light transmitted through both spectra and shows the absorption spectrum of the composite blue. All the coloured rays are quenched, excepting the blue, green blue at lines F and G, and extreme red, A and B,

which combine together in the eye to produce the sensation of a blue (see also § 61). The same result may be represented with the chromatic circle, as in Fig. 17:—

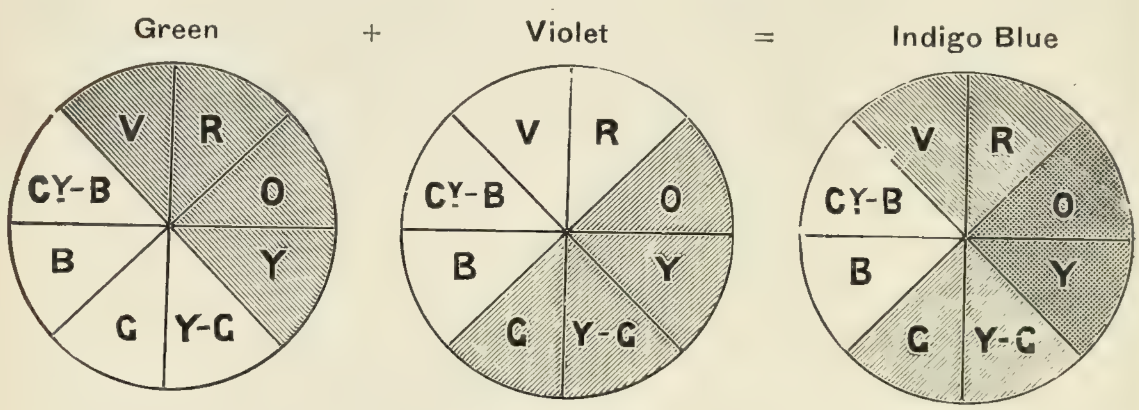


FIG. 17.—Showing formation of a blue by admixture of green and violet.

Though the few examples we have studied are simple, they are sufficient to show the fundamental law that governs all the varied phenomena in the production of colour by absorption, and the science which underlies the simplest experiment in colour mixing.

§ 34. For the careful investigation of all such colour phenomena the spectroscope is invaluable. But it is necessary, in writing about colour and colour absorption, to have some graphic means of representing the various intensities of absorption or of reflection in a colour spectrum. It is a difficult and most unsatisfactory method to represent this by means of shading in varying degrees of depth, according to the degree of absorption, as in Fig. 16; but philosophers have adopted a simple method whereby this difficulty is removed, and one which enables them to express clearly and accurately the various characteristics of any colour. This graphic representation of an absorption spectrum is accomplished by means of a curve, which is drawn on a diagram representing the solar spectrum, with its principal fixed lines to serve as reference marks. These curves can

be made to represent, by their varying heights on the chart, either the different degrees of :—

(1) Luminosity (brightness of the reflected colour) ; or,

(2) Absorption (darkness of the colour in the spectrum).

Some writers on colour employ the *luminosity* curve ; while others prefer to represent the spectrum of a colour by its *absorption* curve. Either of the two methods can be employed, but the writer has adopted, with the exception of Figs. 18 and 19, the *absorption* curve in his diagrams illustrating the various spectra of dyes and coloured fabrics. Though these curves are, for the first time, somewhat per-

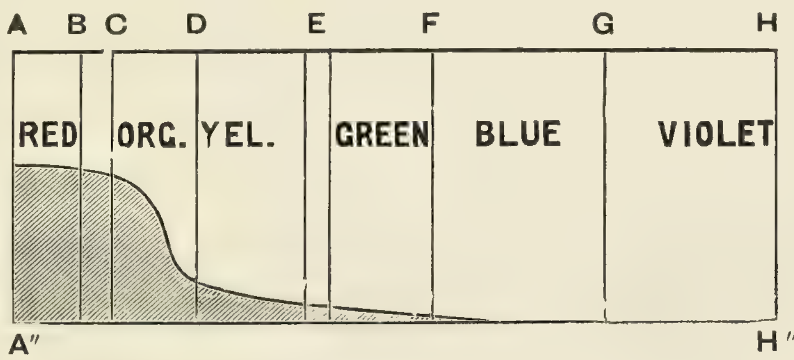


Fig. 18.—Spectrum showing locality and intensity of coloured light transmitted by ruby glass. The shaded curve represents the *transmitted* light.

plexing to the colour mixer and dyer, they are well deserving of study, as they are of much assistance in interpreting many colour phenomena which would otherwise remain to him a mystery ; and they also reveal, at a glance, the optical nature of a colour or dye, which would require pages to describe as fully.

§ 35. (1) **LUMINOSITY CURVES.**—By the first method the brightness of the reflected or transmitted colour is represented by the height of the curve. For example, let the rectangle AH, A″H″, Fig. 18, represent the solar spectrum, with all its different colours arranged in the usual order of red, orange, yellow, green, blue and violet, in their natural

brightness. The letters A, B, C, D, etc., represent the prominent fixed lines present in the sun's spectrum; and are as invaluable landmarks in determining the positions of the different colours. We have already learned that ruby glass transmits the red rays: from A to B, with a little of orange between C and D. This, then, can be represented in diagram form by drawing a curve at that part of the spectrum (see Fig. 18), which will be highest in the red at A and B, showing the part of greatest brightness, while it rapidly falls in the orange between C and D. At the yellow part of the spectrum D it has fallen almost to the base line, showing the small quantity of yellow which ruby glass transmits, while in the green and blue (lines E and F) no light is trans-

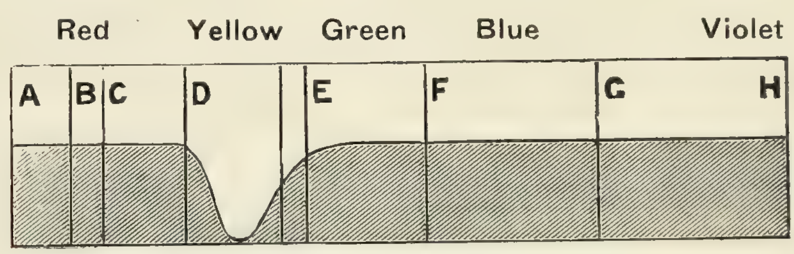


Fig. 19.—Spectrum showing the light transmitted by dilute solution magenta. Here the shaded portion represents transmitted light.

mitted. The quantity or intensity of the coloured light, therefore, which is transmitted or reflected by any coloured body can be represented in this simple manner.

If the colour known as magenta, either in a dilute solution or dyed upon a fabric, be examined with the spectroscope in the same way as the ruby glass, a reflected light curve is obtained which may be represented in Fig. 19, the shaded portion showing the reflected light. It will be seen from this curve that magenta, in its *light tints*, reflects the red, orange and yellow rays to line D, but absorbs all the yellow-green and bright green of the spectrum as far as the lines E, where it reflects all the rest of the rays from the blue to the violet.

§ 36. (2) **ABSORPTION CURVES.**—The second method

is exactly the reverse of the first described, as with it not the brightness or luminosity is represented, but the *darkness* or absorption of the coloured rays.

For the purpose of illustration let magenta be again taken, and its absorption spectrum in Fig. 20 is represented according to two methods, *i.e.*, A by shading the absorbed portions of the spectrum, and B by the absorption curve. It will be seen that the region of absorption lies in the brightest part of the spectrum, namely, from the yellow to the green (from lines D to E). The dotted line represents the absorption curve of a strong solution, or of a deep shade of magenta, showing the much-extended absorption band

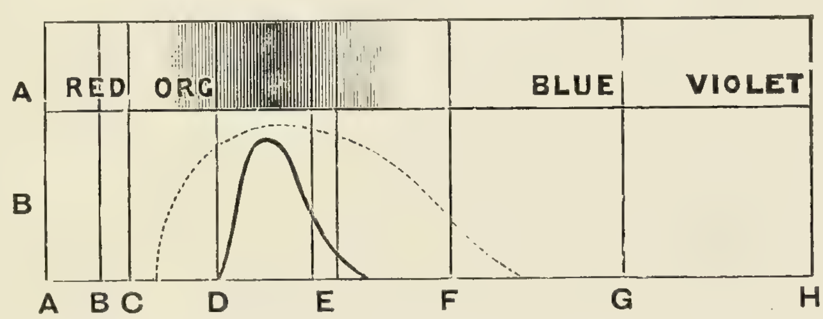


Fig. 20.—Absorption spectrum of magenta represented by shading (A), and by an absorption curve (B). The dotted curve represents a strong solution of magenta showing an increased absorption.

The richer the colour is, or the more concentrated the dye solution becomes, the absorption is the greater, and the light tends, more and more, to become monochromatic. A concentrated solution of magenta transmits only the red rays. The effect produced on deepening a dye solution, or in dyeing colours in varying strengths is an important question to colourists, and will be considered specially under the subject of Dichroism (see § 39).

Fig. 21 represents, in the same way, the absorption spectrum of a green dyed with picric acid and indigo extract. A shows the method of representing the degrees of absorption by shading the spectrum, and B gives the corresponding

absorption curve. It will be observed that the green consists of a *little red* at the lines B to C, *green, blue-green, and blue;* while the remaining red, orange, yellow, most of the blue, and all the violet are absorbed.

In all observations of colours with the spectroscope it is best to employ either the purest sunlight; or, what is considered even better, the electric arc light. In order to give greater accuracy to the descriptions of colour spectra and absorption curves, with only the fixed lines as the reference marks, it is desirable:—

1st, That the *strength* of the colour solution be noted;

2nd, That the *depth* of the colour solution be noted;

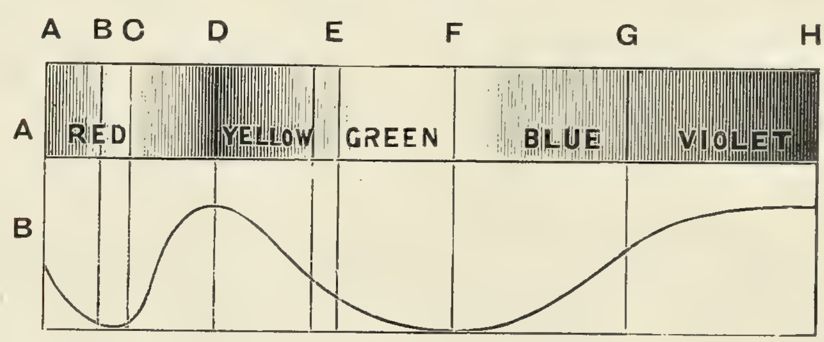


FIG. 21.—Representation of the absorption spectrum of the green produced by the admixture of picric acid and indigo extract. A, intensity of absorption of spectrum shown by shading; B, by the curve.

3rd, That the absorption bands be carefully measured and reduced by an *interpolation curve to their wave-lengths.*

Small absorption curve diagrams, such as we have shown in Fig. 22 and elsewhere, give at a glance an amount of information regarding the optical structure of the colours, which might otherwise require pages of printed matter to accurately describe.

The following characteristic absorption spectra of six well-known dyestuffs may be taken as examples of colour absorption curves:—

1. *Eosine* absorbs chiefly the green and blue-green rays

E to F, while in a strong solution, or deep shade dyed upon wool (see dotted line), the absorption band is extended from nearly D in the yellow to beyond the line F in the blue.

2. *Orange G.*—There are many azo oranges, all of them giving a more or less similar spectrum. The orange here represented shows all the blue and violet end of the spectrum absorbed as far as the E lines in green, where

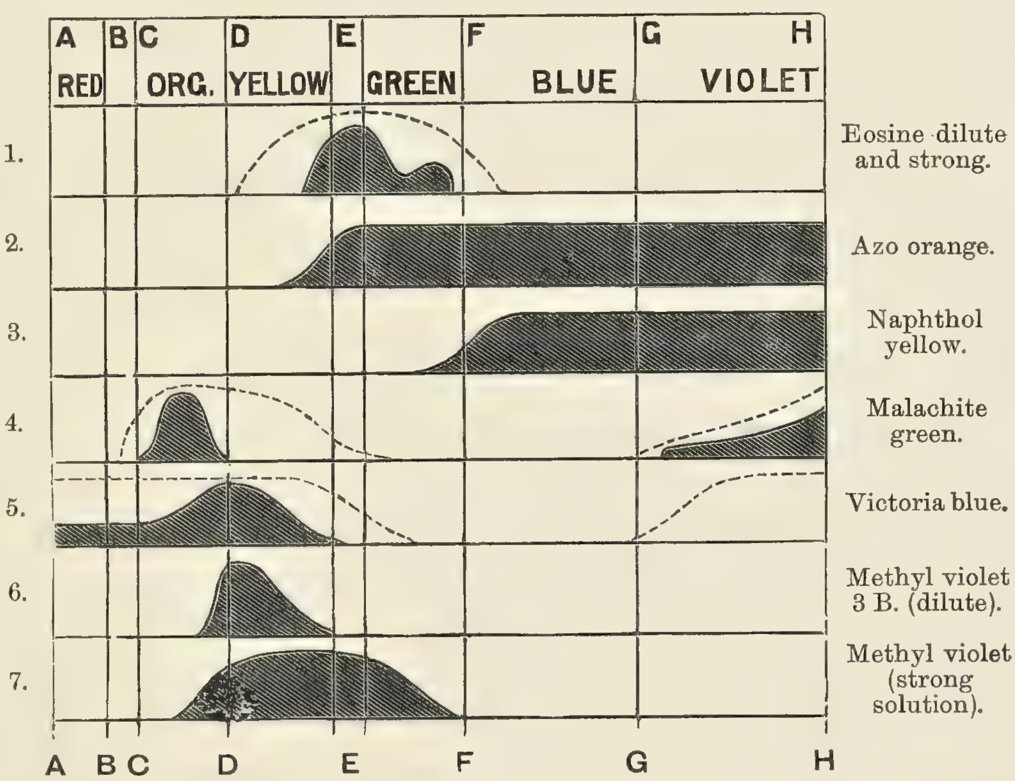


FIG. 22.—Examples of absorption spectra of dyestuffs. The dotted lines at 1, 4 and 5 represent strong solutions of the colouring matters, showing increased absorption.

absorption gradually ceases towards D. The yellow, orange and red are freely transmitted.

3. *Naphthol Yellow* shows absorption of all the violet and blue violet to the F line, where the absorption stops short in the blue green, and gradually decreases towards the green. If the yellow be of a greenish cast, a

slight absorption may be observed in the red. The spectrum of yellow is an instructive one, as it shows us that yellow dyes or paints are not yellow because they reflect only yellow rays, but because they absorb or quench all those rays complementary to the yellow, *i.e.*, the blue and violet. The red, orange and green rays are reflected as freely as the yellow ones, but on entering the eye they are combined to form white light, so that the yellow from naphthol yellow, picric acid or any other yellow dye, is not a pure colour, but consists of yellow rays largely diluted with white light (see also § 25).

4. *Malachite or China Green.*—The rich blue-green colour given by this aniline dyestuff shows a strong absorption in the red-orange of the spectrum, extending midway between the lines C and D, with a faint absorption of the extreme violet. In a more concentrated solution (see dotted curve) the orange-red, orange, yellow and yellow-green and extreme violet are absorbed, extending from B to nearly the E lines in green, and from G to H. On viewing a deep solution of this dyestuff, it shows a redder hue than when dyed on a fabric, owing to the property of dichroism (see § 39 : also coloured Plate II., Fig. 6). It is observed from this spectrum that malachite green transmits a large quantity of red light, along with the green, blue green and blue. Such a blue-green cannot produce so brilliant and clear a tone of green, as one showing a greater absorption in the red.

5. *Victoria or Night Blue.*—This is a beautiful pure tone of azure blue, and from its spectrum is seen to absorb a certain quantity of red, gradually increasing in absorption until yellow is reached (D), where the absorption is strongest. The curve line gradually falls as it approaches green, at the E lines, after which there is free transmission of all the other colours of the spectrum. This blue, from its tendency to absorb red, and freely reflect all the green

and blue, preserves its beautiful pure colour in gaslight, and hence often receives the name of "night" blue.

6 and 7. *Methyl Violet* shows strongest absorption in the bright part of the spectrum, in the yellow and yellow green, while the red, orange-red, blue-green, blue and violet are freely transmitted. 7 is a strong solution, and shows the greatly increased absorption—the band extending from the lines C to F. This shows that the magnificently rich violet colour of this aniline derivative—unequalled by any other colouring matter—is not due simply to its free transmission of the violet part of the spectrum, but to its absorption of those rays *complementary* to violet, namely, yellow and yellow green. It is an interesting fact, which might be mentioned here, that the yellowish green metallic reflection of this dye, when in the solid, crystalline state, consists of that part of the spectrum which is absorbed when in solution, namely, yellow and yellow green. See § 13.

§ 37. As nothing in nature is ever totally lost or destroyed, the inquiring colourist may ask himself the question: "What becomes of these coloured rays which are absorbed within a coloured substance?" They become changed from visible light into an invisible force, namely, *heat.* This explains the reason why black clothes are so warm to wear on a sunshiny day, compared with light-coloured ones.

All the light of the sun's rays is absorbed within the black material, and is there transformed into heat; while a light coloured suit of grey, or white, absorbs little light and reflects much, and is, therefore, not warmed by the absorption of the light rays. This may be strikingly demonstrated by placing two pieces of velvet, one white and the other dyed black, upon a bed of snow during bright sunshine. After some time has elapsed it will be found that the black velvet, by its absorption of the rays of light, has become warmed

and sunk down to a considerable depth in the snow, by reason of the snow being melted by its heat; while the white piece of material remains on the surface in the same position as when first placed. Having reflected all the sunlight from its surface, it has not become heated by absorption. All coloured materials absorb more or less of the sun's rays, and are accordingly warmer in bright sunshine than white material.

§ 38. All the examples we have given of the spectra of coloured materials and dyes show clearly the inability of the naked eye to distinguish between a pure and compound colour. Two colours dyed on cloth may appear identical to the eye and yet be composed in a totally different manner and show different absorption spectra when examined with the spectroscope. Hence arises the great value of the analysing powers of the prism in revealing the true composition of any colour, by separating its several constituent coloured rays.

By carefully examining bright, or what are termed *luminous*, colours, like magenta, the eosines, or rhodamine pink—one of the most brilliant colours known to the dyer—it will be found that their brilliancy of hue is not due simply to the fact that they reflect or transmit that colour only; but because they absorb all the green and yellow-green part of the spectrum, leaving the red, orange, yellow, blue, and violet, to be transmitted, which produce, when they are all combined upon the retina of the eye, the impression of the beautiful magenta, or eosine-pink colour. But these coloured rays are present in such proportions as to produce, by their combination, a certain amount of white light, so that the brilliancy of magenta, rhodamine and such like colours is due largely to the formation of white light by the reunion of many of the coloured rays. We have already considered the case of naphthol yellow and picric acid (see

§ 36, example 3), which owe their luminosity to the combination of the complementary colours producing white. It is to the presence of this recombined white light that a dye owes its brilliancy.

The sharper the absorption bands appear in a colour, the more luminous is that colour; and when a dye shows more or less absorption all over the spectrum it can never be a bright and luminous colour.

§ 39. Before leaving the subject of colour absorption, it is necessary to pay attention to the interesting property of *dichroism*, possessed by nearly all ordinary colouring matters. If a ray of white light be passed through a strip of gelatine or glass coloured yellow, the transmitted light will of course be of a clear yellow colour. If, however, three or four similar strips be placed together and viewed through, it will be observed that the light is not a yellow similar to that obtained by viewing through the one coloured film, but it has acquired a more orange appearance (see 5, Plate II.). If the number of coloured strips be doubled, the light transmitted will be of a deep orange colour, and should the colour be transparent enough it might be possible to increase the number of yellow plates until a *red* colour was transmitted. The same phenomenon may be noticed in a solution of magenta. If the solution be very dilute, or the layer of colour be exceedingly thin, a beautiful bluish-pink colour is transmitted; but if the solution be strengthened, or its depth be increased, the blue cast of hue vanishes and the magenta assumes a scarlet or even a ruby-red colour (see Fig. 4, Plate II.). From these simple experiments it may be seen that the colour of the transmitted light depends greatly on the strength of the colouring matter, or on the depth of the colour solution, through which the light has to travel. This change of hue or *dichroic* property is very marked in some substances, chromic chloride, for example,

which is a green in thin solution, and in a deep solution it assumes a claret red (see Fig. 23). A great many dyestuffs exhibit this property in a more or less marked degree, and those which show it strongly had better be discarded by the dyer and textile colour printer, as they produce differences in hue between plain-surfaced and velvet-pile fabrics dyed with the same colouring matter; and likewise, in a series of

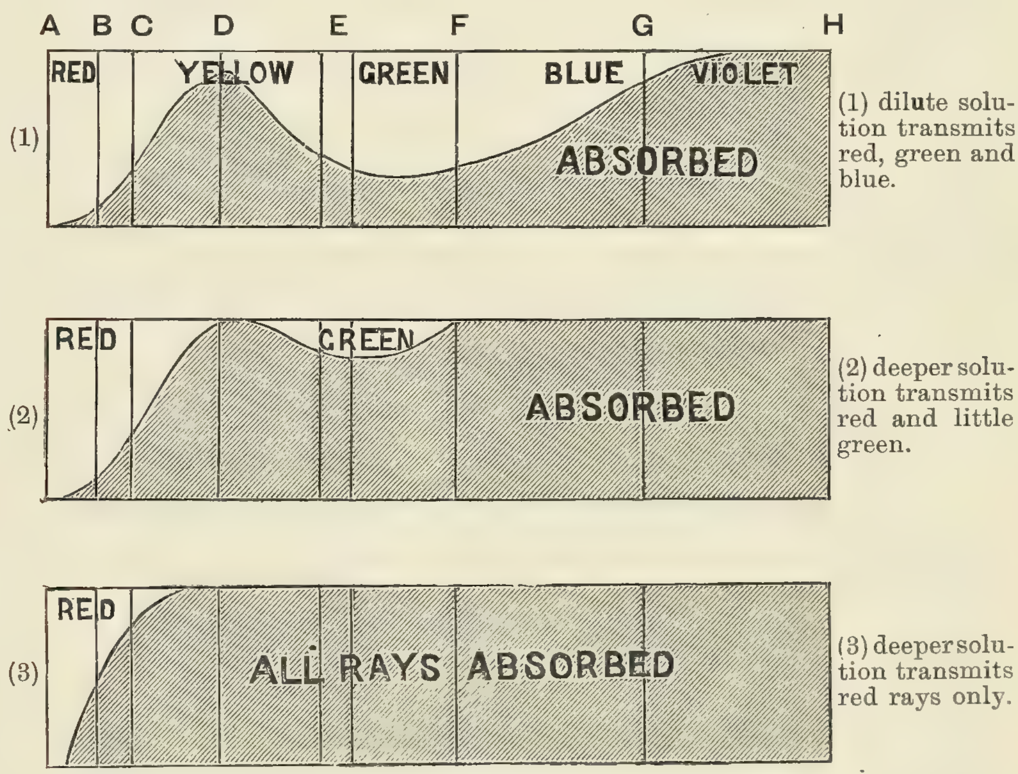


Fig. 23.—Absorption spectrum of chromic chloride, showing its change in colour from a green in thin solution (1); a dull red in a deeper solution (2); and a red in (3), where all rays are absorbed except the red.

gradating or stepping shades a different cast is produced in the lighter tints, which often proves disappointing to the colourist. For the effects of dichroism in dyeing see § 40.

Solutions of malachite green, archil, litmus, indigo extract, quinoline blue, methyl violet and others show that the greater the depth of their solutions, or the more concentrated their colour, the redder in tone they become. They gradually lose, as their depth or strength increases, the green or blue

rays observable in their more dilute solutions. One of the most interesting examples of a dichroic colouring matter is quinoline blue, an aniline dyestuff which has now fallen into disuse. In dilute solution, or in a thin layer, it possesses a beautiful clear blue colour, while in a deep layer it assumes a fine red (see 2, Plate II.). This interesting property of dichroism may be readily studied by making a spectroscopic examination of the colouring matter with varying depths of solution. It is not an easy matter illustrating dichroism by means of a coloured plate; but on plate ii. will be found a few representations of dichroic colouring matters.

No. 1 is a curiously dichroic sage colour made from an aniline yellow or fustic and methyl violet. In its light tints, represented by the edges of the single plates, it is of a sage or olive hue; while in its deeper tones it changes to a plum shade, then to a dull plum red. The coloured illustrations represent three different depths of the colouring matter: (1) dilute, (2) medium, and (3) deep—the deep solution being shown where all the three plates overlap each other.

No. 2 represents the change of hue in quinoline blue, which has just been described.

No. 3 is methyl violet, showing its change from a bluish violet in dilute solution to a claret in deep solution. In velvet-pile or cut surfaced fabrics, this dichroic red hue is quite observable, and is produced by the repeated reflections within the depths of the fibres (see § 40).

No. 4 represents the effect of deepening a solution of magenta, or of any of the aniline pinks, such as eosine, rhodamine, etc. They show a bluish-pink hue in dilute solution, or in their tints, which is lost on deepening the colour, when they assume a scarlet or ruby-red hue (see also Diagram 24).

No. 5 shows the result often obtained while preparing a gradating series of yellows. The light tint may show a clear

greenish hue, but in the deeper tones the yellow may assume an orange cast. This effect is very noticeable with a solution of bichromate of potash, gamboge, and many of the aniline yellows.

No. 6 may be taken to present something like the effect of viewing different thicknesses of malachite green solution, showing its change in hue from a blue-green to a purple.

The following table gives a few examples of such changes in the hue of a colour :—

Colouring matter.	In thin layer.	In deep layer.
Magenta (see Fig. 4, plate ii.) . .	Bluish pink.	Scarlet, or red.
Cochineal carmine	Bluish pink.	Red.
Eosine and rhodamine pinks . .	Rose pinks.	Scarlets.
Picric acid	Greenish yellow.	Pure yellow.
Gamboge (See Fig. 5, plate ii.) . .	Yellow.	Orange.
Bichromate of potash (see Fig. 5, plate ii.)	Yellow.	Deep orange.
Chromic chloride	Green.	Claret red.
Sulphate of copper	Greenish blue.	Pure blue.
Prussian blue	Sea-green blue.	Deep blue.
Quinoline blue (see Fig. 2, plate ii.) .	Clear blue.	Fine red.
China green	Bluish green.	Blue violet.
Above with few drops acid . . .	Yellowish green.	Claret red.
Malachite green (see Fig. 6, plate ii.) .	Blue green.	Reddish purple.
Litmus	Blue.	Claret red.
Acid extract of indigo	Greenish blue.	Purply blue.
Methyl violet (see Fig. 3, plate ii.) .	Blue violet.	Red violet.
Above with few drops acid . . .	Violet blue.	Claret red.

In examining such colours with the spectroscope, a very dilute solution is first examined, and the absorption bands are carefully noted. The strength of the solution, or the thickness of the layer, is then increased, and the change in the absorption bands determined. It will be observed that, as the strength of the colour solution increases, the dark bands in the spectrum become broader, and one colour after another is gradually absorbed, until, in many cases, an almost monochromatic colour is transmitted. In such investigations a wedge-shaped prism or bottle, for holding the dye solution under examination, is generally employed, as it shows a gradual increase in the depth of the colour.

Plate II.

Fig. 1.

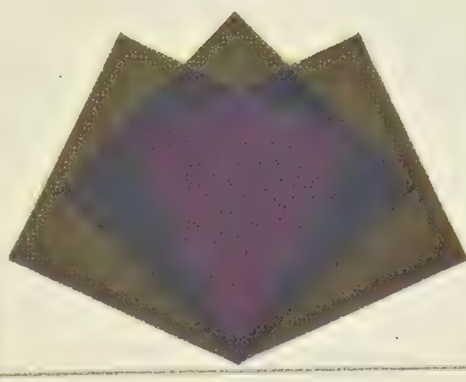


Fig. 2.

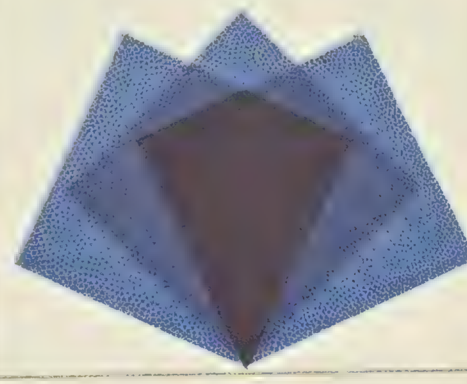


Fig. 3.

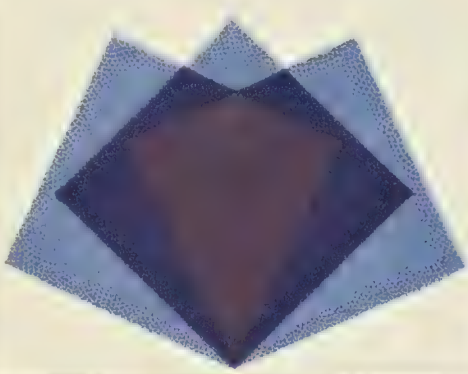


Fig. 4.

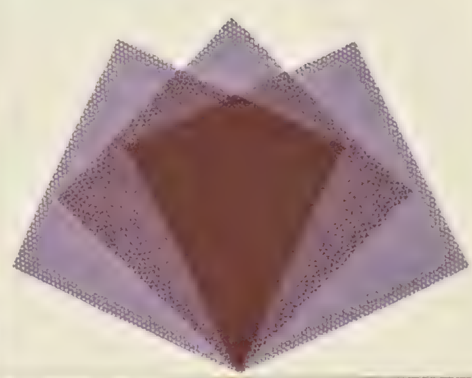


Fig. 5.

Fig. 6.

This plate illustrates the effects of Dichroism in Dyes, and represents three depths of the colour solution. (1) Sage Colour produced from Naphthol Yellow and Methyl Violet; (2) Quinoline Blue; (3) Methyl Violet; (4) Magenta; (5) Gamboge and some Aniline Yellows; (6) Malachite Green and other Aniline Greens. Note the difference in hue as the solutions are deepened. [*See* Chapter IV.]

Fig. 24, which is drawn from the writer's own experiments, shows clearly the gradual increase in the absorption band of the beautiful pink dyestuff named rhodamine, a phthalein derivative. A dilute solution of $\frac{1}{4}$ centimetre thickness presents a very delicate bluish-pink tint, and shows two absorption bands, one in the yellow green, $D\frac{1}{2}E$, and the other in the pure green at E. The absorption is

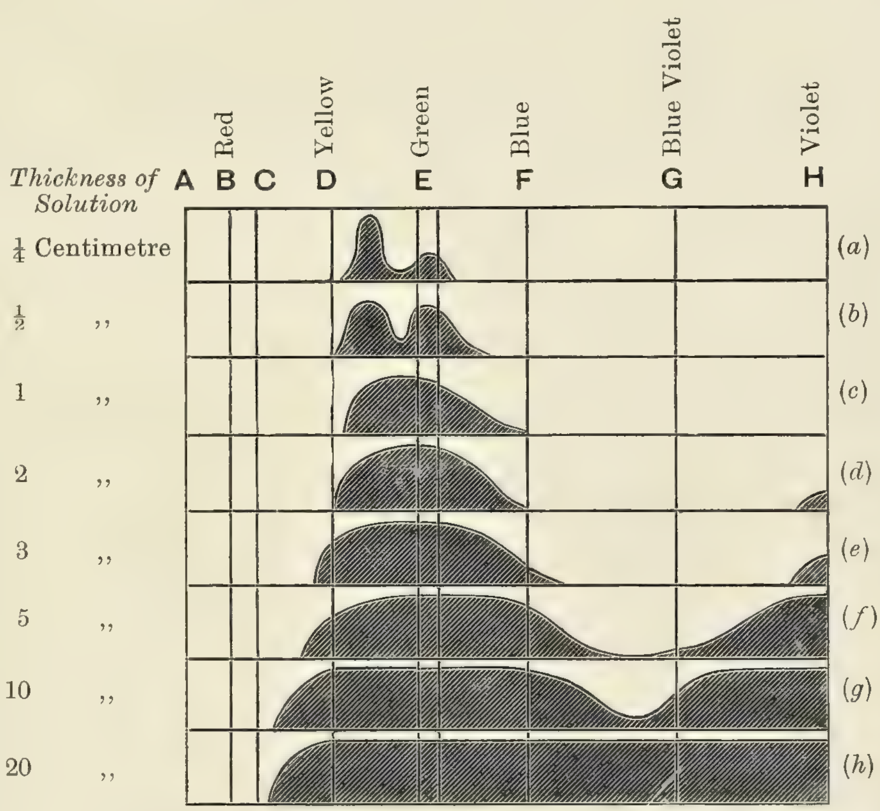


FIG. 24.—Showing gradual increase of absorption band of rhodamine pink on deepening its solution. The colour varies from a delicate bluish-pink (*a*) to a pure scarlet (*h*) at 20 centimetres thickness.

strongest in the yellow green (see (*a*)). The same dye solution, increased to $\frac{1}{2}$ centimetre thickness, appears to the eye a light magenta tint, which, on examination with the spectroscope, shows an increased absorption, the bands in the yellow green and green becoming denser and broader [see (b), Fig. 24].

If the solution be increased to 1 centimetre thickness,

one strong and decided absorption band is observed, the two bands having joined together, extending from immediately beyond the D line in the greenish yellow, through the E lines in the green, and gradually decreasing in absorption towards line F in the blue green [see (*c*)]. At 2 centimetres thickness, when the rhodamine solution assumes a rich magenta hue, a further increase in absorption is noticed, the band extending from D in the yellow to F in the blue green, and also a slight decrease in the violet rays is observed.

At 3 centimetres a still further absorption takes place, and this increases gradually until at 5 centimetres the dark band extends from C$\frac{2}{3}$ D in the orange to azure blue, F$\frac{1}{2}$ G, the blue being transmitted, absorption commencing again at the blue-violet, and continuing to the end of the spectrum.

At 10 centimetres thickness the solution, on viewing through that depth, is of a crimson-red hue, and from its absorption band [see (*g*)], consists of red and orange red from A to C and azure blue between the lines F and G, all the other rays of the spectrum being absorbed.

At 20 centimetres depth, (*h*) spectrum, the solution appears to the eye of a deep scarlet or ruby-red colour, with no trace of a bluish or magenta hue. Its spectrum shows all the blue rays are now absorbed, and total absorption extends from the violet end through all the colours to nearly C in the orange red, so that the transmitted light consists of only red and orange-red rays.

This example of rhodamine has been taken in detail, as it furnishes a good instance of what is termed *selective* absorption or dichroism, showing how a colouring matter in dilute solution reflects or transmits a large number of coloured rays which are gradually one by one absorbed as the colour is strengthened or its solution deepened.

In all such cases as we have given, the rates of colour absorption differ from each other; certain coloured rays are

absorbed and disappear, while the others are more freely transmitted. Hence the transmitted light, being the sum of all the unabsorbed rays, must vary in its composition according to the concentration of the coloured solution, or the depth through which the light has traversed.

§ 40. The phenomenon of dichroism is one of much importance to the dyer and colourist, as the same effects of selective absorption are observed when colours are dyed upon fabrics, or pigments are mixed upon the artist's palette. Thus it will often be found that reds, when diluted to make tints, go off into an orangy cast; while blues, instead of reducing into pure tints of blue, become either greenish blues or reddish blues. Yellows, too, are often noticed to become buffy when reduced to form a light tint.

The behaviour of a colouring matter on dilution is a point of much importance to the dyer, because it is evident that a deep tone of blue or red may not give an equally balanced colour series, stepping gradually from the deepest tone to its lightest tint, without requiring to be tempered with another colouring matter to keep the series in a harmonious gradation (see Chapter V.).

A colour dyed on a velvet fabric having a plush pile is sometimes found to present a different hue from the same dyestuff when printed on calico or dyed on a plain-surfaced fabric. The repeated reflections within the minute interstices of the dyed velvet pile act in the same manner, and give the same effect, as the deepening of the colour solution, which results in the selective absorption of certain coloured rays. Thus, to take the example of quinoline blue as being the most characteristic, a plain surface of tapestry, or of calico, dyed with this colouring matter will appear much bluer in hue than when the same dyed material is cut into a velvet pile. In velvet material the light penetrates deeply among the fibres, and becomes enriched by repeated internal

reflections. At each reflection a minute quantity of the blue and green rays is absorbed, which gradually increases the percentage of the red rays until, as in its deep solution, the reflected light, after being robbed of its bluer rays, assumes a much redder hue.

§ 41. It will always be observed that colouring matters which show a tendency to transmit the red rays more readily than the blue and violet ones, appear much redder in artificial light, like gas, oil lamp, or candle light. The quinoline blue, for example, is a fine blue by daylight and a reddish violet by gaslight, owing to the facility with which it transmits red rays. This may also be noticed with dyed shades of methyl violet, which redden more in gaslight than a similar shade dyed with a non-dichroic violet.

Dichroism also explains the peculiar reddish tone seen on some of the aniline violets when dyed on silk.

Acid extract of indigo (indigotin disulphonic acid) is slightly dichroic, transmitting the red rays more freely, and this causes it to appear redder in gaslight than other blues, which may match it perfectly in daylight. Several colouring matters, when combined to form compound shades, show a very decided dichroistic property which makes them objectionable for dyeing. In such cases the lustre of the fibre and the texture of the dyed fabric effect a marked change in their appearance. Peculiar olive green shades can be made by dyeing with naphthol yellow or fustic and methyl violet or acid violet (7 B), which show this property in a remarkable degree; appearing sages and olives on plain fabrics and calico, but changing to bronze and plum shades on a cut-surfaced or velvet pile. But we cannot enlarge further on this interesting branch of colour science. (For difficulties experienced in examining and matching such shades, the reader may consult the companion work on *Colour Matching on Textiles*.)

CHAPTER V.

COLOUR PRIMARIES OF THE SCIENTIST *VERSUS* THE DYER AND ARTIST—COLOUR MIXING BY ROTATION AND BY DYEING — SECONDARY AND TERTIARY COLOURS — CONSTANTS — HUE, PURITY, BRIGHTNESS — TINTS, SHADES, SCALES, TONES, SAD AND SOMBRE COLOURS—COMPLEMENTARY COLOURS.

§ 42. Except in special cases of defective colour vision, the optic nerve is so constructed as to be capable of distinguishing three elementary colour sensations or primary colours, which produce, by their various degrees of combination, all the innumerable mixed shades to be found in nature. What these three primary colour sensations are has long been a moot point with philosophers; but, at the present day, nearly all authorities agree in selecting red, green and violet as the three elementary sensations of colour.

This theory was propounded as early as 1802 by Dr. Thomas Young, but it received little attention until, in recent years, it was re-established and developed by Helmholtz, Clerk Maxwell and other scientists. This theory is now generally adopted as the true one, as it explains satisfactorily all the various colour phenomena. It must not be forgotten, however, that in 1792 the German philosopher Wunsch selected these three so-called primary colours, which are now accepted as the best combination. But, wondrous to relate,

this, the true primary theory, as expounded by Young and Helmholtz, seems to have been anticipated, centuries before, by the mighty "Master of those who know," Aristotle (300 B.C.). In his *Meteorologica*, iii., 2, he says :—

"The colours of the rainbow are those which, almost alone, painters cannot make. For they compound some colours; but *scarlet, green* and *violet are not produced by mixture*, and these are the colours of the rainbow."[1]

The old and most prevalent idea which has been known to painters and dyers from the earliest times is that **red, yellow** and **blue** were the three elementary colour sensations. This theory, however, is wrong as regards the mixture of absolutely pure colours such as found in the spectrum, *i.e.*, coloured lights; but it is the only applicable standard for painters, dyers and all those employing ordinary impure colours. If we might so express it, *the red, green and violet are the theoretical primaries of the philosopher dealing with pure coloured lights; while the red, yellow and blue are the practical primaries of all workers in ordinary colours like pigments, dyes, etc.* As the two theories are apt to prove confusing to the beginner, a few words of explanation may be useful.

The red, yellow and blue theory owes its origin to a mis-interpretation of the phenomena observed in mixing coloured pigments, dyes or superposing coloured glasses, etc. The most distinguished defender of this doctrine was Sir David Brewster, hence it is often known as the "Brewster theory". The laws regulating its phenomena have been elaborately wrought out by Chevreul, Hay, Redgrave, Field and others, and as it proves the only applicable standard to dyers and colourists, it must ever remain their cherished theory. As we proceed, however, we shall understand

[1]For this extraordinarily prophetic statement, the writer is indebted to Mr. W. Benson, in his beautiful work, the *Principles of the Science of Colour*.

more clearly the true interpretation of the various colour-mixing phenomena.

In many cases the two theories have given rise to confusion of ideas. The student must ever bear in mind that the scientifically true primaries of the philosopher, who mixes pure spectrum colours and coloured *lights*, is one standard; while the convenient primaries, red, yellow and blue of the artist and the dyer, is an altogether different standard.

And why? *Because the two theories are based on totally different colour phenomena.* In mixing coloured lights it is a question of *addition:* in mixing dyes and pigments it is a matter of *subtraction.* The former may be represented by a plus (+) sign, the latter by a minus (–). When coloured lights are combined, the sum of the two is the result. If the two coloured lights be complementary to each other, white light is produced. But if two complementary coloured dyes, paints or glasses be mixed, a grey is produced; or, if the colours be sufficiently strong, a black is the result. All the coloured rays transmitted through the one are absorbed or quenched by the other, as we have already seen in Chapter IV., Fig. 15 (see also the dyed specimens on Plate I. at end of book). Each colour subtracts from the other the rays which it does not itself transmit. It is the absorption of certain coloured rays with the reflection of others that produces the innumerable shades to be found in nature and art.

§ 43. The various methods of mixing colours employed by the physicist, *i.e.*, by rotating coloured discs, superimposing by reflection one colour upon another, or casting, by means of a lantern, coloured lights upon a white screen, etc., are all unsuitable to the dyer, and of no service to the mixer of ordinary everyday colours. A few examples might be given to illustrate this. Thus, if a deep shade of blue,

dyed with acid violet 7 B, and an orange yellow, composed of 2 of naphthol yellow, and $1\frac{1}{2}$ of orange G, be mixed together in the dye-bath, a very deep maroon, or even a black, is produced. But, if the *light* from these two dyed colours, the blue and the orange, be combined together, the result is not a maroon, nor anything like it, but a light *pink*, approaching almost to a magenta tint. The greater the portion of the blue light, the pinker the combined hue.

One of the simplest methods of combining the *lights*

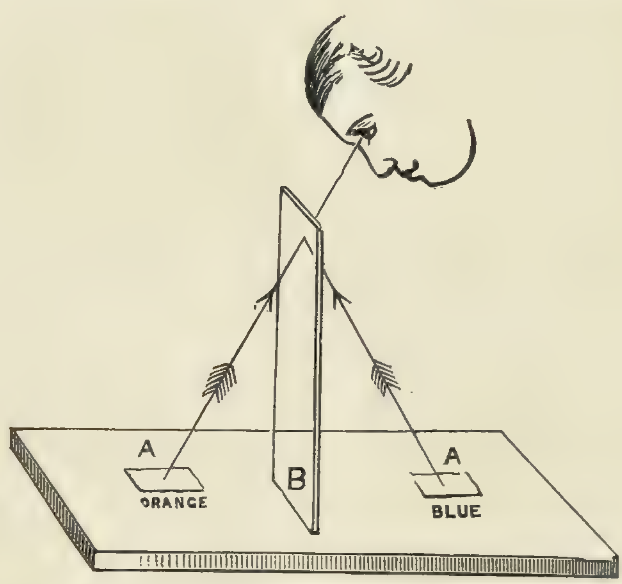


FIG. 25.—Mixing coloured lights by Lambert's method.
A A = colours to combine. B = sheet of glass.

reflected from the surfaces of coloured objects is that devised by Lambert in 1760. The two coloured materials are laid side by side upon a piece of black cloth placed upon a table. A piece of clean glass is placed upright between them, and, by looking through the glass at a certain angle, the reflected images of the two coloured surfaces will be combined, one upon the other, as in the illustration. By slightly inclining the glass plate from the perpendicular position, either towards the one colour, or the other, it is possible to strengthen or reduce the proportion of the coloured light.

Plate III.

Coloured Lights combined.	Dyes and Pigments combined.

Fig. 1.

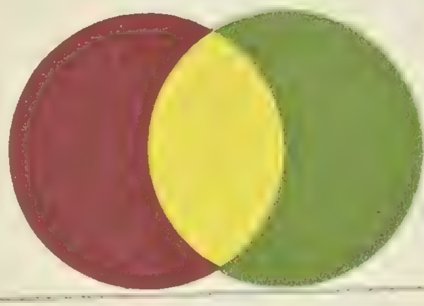


Fig. 2.

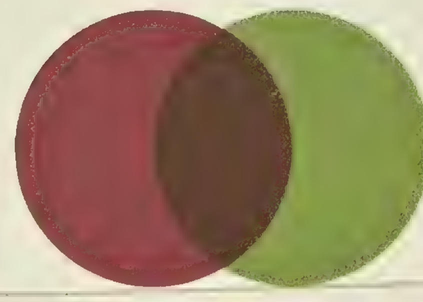


Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

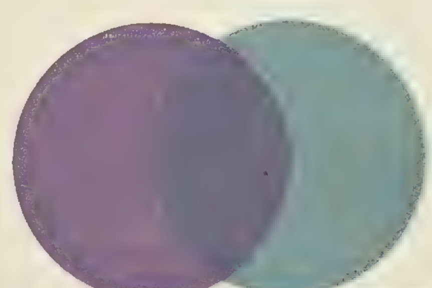


Fig. 7.

To show the very different results produced by mixing Coloured Lights *versus* Dyes.

[*See* CHAPTER V.]

This is a simple and instructive experiment which every colour student may profitably perform for himself. In the example we have just described, when the light from the orange predominated over that of the blue, a greyish pink was produced, while the *vice versâ* gave a light violet pink. If, in the same manner, the light from a piece of cloth, dyed an emerald green, be combined with the light from a bright eosine, or rhodamine pink, a greyish white is produced; which truly represents the effect of the combination of complementary coloured lights. If, however, a piece of material be dyed in the dye-bath with rhodamine pink and a bright green, a series of reddish browns or russets are obtained if the pink be in excess, or, if the green predominates, a series of blue greys is the result. This might readily be guessed by the examination of their combined absorption spectra.

Complementary coloured *lights*, therefore, when combined, produce *whiteness;* while complementary *dyes* and pigments produce *blackness*. By mixing blue and yellow lights a greyish white is produced, which is in accordance with the facts just mentioned; whereas, in dyeing and painting, as every one knows, a green colour is the result of their combination (see Figs. 3 and 4, Plate III.). We have learned in Chapter IV. the correct interpretation of such absorption phenomena.

The following are a few examples showing the different effects produced by mixing colours: (1) by the philosophers' method, namely, by the rapid rotation of the coloured discs, and (2) by the dyers and painters' method (see also Plate III.). The colours chosen are, as near as possible, representative colours, dyed upon wool or silk fabric.

Colours mixed.	Shades produced by dyeing.	Shades produced by rotation.
Naphthol yellow Victoria blue .	Fine green.	Grey.
2 R scarlet . Azure blue . .	Maroon or black.	Reddish purple tint.
Red . . . Yellow green .	Terra cotta shade.	Very pale pink.
Acid magenta . Green . .	Dark red, or a violet.	Pale reddish pink.
Red, deep shades Green . .	Black.	Grey.
Methyl violet . Yellow green .	Dark plum shade.	White.
Yellow . . Methyl violet .	From dull sage to a claret.	Yellowish white.
Orange . . Deep violet .	Dull crimson.	Light bluish pink.
Blue . . . Red . . .	Deep red or maroon.	Violet purple.
Purple . . Green . .	Dark green or sage.	Grey.

A sufficient number of examples have been given to illustrate how the mixing of colours by the rapid rotation, or any other similar method employed by the physicist, is altogether unsuitable for the dyer, printer, artist, and all those engaged in the *practical* mixing of colours.

Plate III. illustrates the different results obtained by mixing coloured *lights* in comparison with that of *dyes* and pigments.

Red and green lights combine, as in No. 1, to form the sensation of yellow, while in dyeing and ordinary colour mixing a grey or black is the result, as in No. 2.

Blue and yellow lights when combined produce white light 3—indistinguishable by the naked eye from the ordinary white daylight composed of all the spectrum colours. The spectroscope or prism, however, would reveal the difference.

Blue and yellow dyes, as we already know, produce not white but green, as in No. 4.

Nos. 5 and 6 (Plate III.) show the difference between mixing pink and sea-green lights, and pink and sea-green dyes. In the former a faint bluish-pink tint is obtained, approaching almost to a white; while in dyeing, a beautiful shade of violet is the result. By combining the blue and yellow of No. 7 by Lambert's method (see Fig. 25) a greyish white is produced, instead of a green.

For many years it was supposed that the results given by these two methods of colour mixing, namely, by dyeing or painting, and by rotation, were identical; but, after a few experiments such as we have stated, it is seen that they are by no means the same. Lambert, in his famous investi-

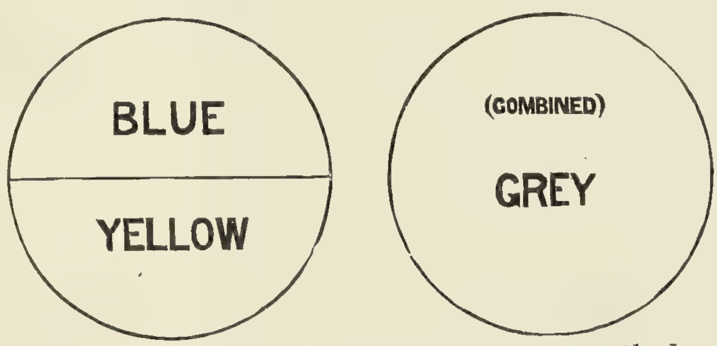


Fig. 26.—Diagram illustrating Lambert's method.

gations on colour about 1760, found that by combining blue and yellow lights, in the manner shown in Fig. 25, he obtained not a green but a *white*.

If we take a cardboard disc like Fig. 26, one half of which is painted with ultramarine blue and the other with a pale chrome yellow as shown in No. 7 of coloured Plate III., and rotate it quickly before the eye, so that the blue and yellow are mingled upon the retina of the eye, there is produced not a green, but a grey, slightly tinged with yellow. If the proportions of the blue and yellow be carefully adjusted it is possible to remove this tinge of yellow and obtain a pure neutral grey. This same result may be found by combining the blue and yellow by means of the Lambert method, *i.e.*, by placing a sheet of clean plate glass on the

line AB of Fig. 7, when, by looking through the glass in a manner similar to that shown in Fig. 25, the image of the yellow overlaps that of the blue and a dull yellowish grey is seen as the result of their combination. By slightly tilting the glass from the vertical position, the proportion of the yellow or the blue light may be varied until a fairly good grey tint is obtained. These simple experiments therefore show that the Brewster theory of yellow and blue producing a green, does not hold good so far as coloured lights are concerned. If instead of the blue and yellow pigments we used *lights*, or the pure spectrum colours, the result would be a pure white light instead of a dull grey.

As this little manual is intended for dyers, calico printers, and others who must adopt the practical primaries, red, yellow, and blue, we need not enter further into the various methods employed by the physicist in mixing coloured lights; but would refer the reader to the larger works on colour physics.

§ 44. In mingling two coloured pigments or dye solutions, the resultant colour is due, as we have already seen, to the double absorption or subtraction which the light has undergone. What remains over is the coloured light which emerges unabsorbed by either of the mixed colours. For several reasons it is necessary for the dyer and colour mixer to keep to the old primaries of red, yellow and blue, which, with the addition of black and white, produce all the colour sensations the eye is capable of perceiving. The black and grey can be produced by mixing these three primaries together. Having, therefore, decided on the Brewster triad —*i.e.*, red, yellow and blue—it may be well to introduce the **Secondary Colours**, orange, green and violet, thus:—

Red + yellow	produces	orange.
Yellow + blue	,,	green.
Blue + red	,,	violet or purple.

(See Coloured Frontispiece, also Fig. 27.)

The dyer, by varying the proportions of the primaries, can obtain innumerable gradations of hue; thus in the case of orange a series can be made ranging from an orange red on the one hand to an orange yellow on the other, thus:—

Secondary Colours.

3 Red + yellow = orange red.
2 Red + yellow = red orange.
Red + yellow = orange.
Red + 2 yellow = yellow orange.
Red + 3 yellow = orange yellow.

The production of the secondary colours by the combination of two of the primaries is seen in Plate I. (frontispiece) and also at Fig. 27, page 75. In the same way a great variety of greens, ranging from greenish yellow to a blue green, and of violets from a blue violet to a red or purple hue can be produced by varying the proportions of the two primaries.

TERTIARY COLOURS.

§ 45. **Tertiary Colours.**—What are termed tertiary shades are those produced by the combination of all the three primaries. The third primary colour, however, does not produce a new *hue*, but merely plays the part of dulling or saddening the other two by forming a certain amount of grey or black by its combination; hence the many indescribable shades used in the Arts, and known as tertiaries, are simply the primary or secondary hues dulled with grey.

In the frontispiece (Plate I.) is shown the tertiary shades produced by the combination of two secondaries. Green and orange combine to form olive or *citrine*. Orange and violet produce a reddish brown or *russet;* while green and violet give a blue grey or a *slate* hue (see Fig. 27). But, if we examine carefully the formation of these so-called tertiary shades, bearing in mind that the three primaries together produce grey or black, it will be found that they are

nothing more than broken, or dulled tones, of the primaries and secondaries.

Let the symbols R, Y, B stand for red, yellow and blue, and we may analyse the tertiary shades as follows :—

$$2\,Y + R + B = Y + \text{grey} = \text{yellow-grey or citrine.}$$
$$Y + 2\,R + B = R + \text{grey} = \text{red grey or russet.}$$
$$Y + R + 2\,B = B + \text{grey} = \text{blue grey or slate.}$$

Thus the three shades—citrine or olive, russet and slate—are simply the three primaries, yellow, red and blue, flattened with a quantity of grey. This is clearly illustrated in the coloured Plate IV., where the three primaries are mixed with a neutral grey, when these three tertiary shades are produced (see Plate IV.).

There are six normal tertiary shades altogether, the other three (sage, buff and plum) being produced by an excess of two primaries, thus forming dulled tones of the secondaries, green, orange, and violet. These may be represented as follows :—

$$2\,Y + R + 2\,B = Y + B + \text{grey} = \text{green grey or sage.}$$
$$2\,Y + 2\,R + B = Y + R + \text{grey} = \text{orange grey or buff.}$$
$$Y + 2\,R + 2\,B = R + B + \text{grey} = \text{violet grey or plum.}$$

From the above it will be observed that the more colours there are in a mixture the duller or sadder is the colour produced, as a greater quantity of black (caused by absorption) is formed by their combination. This forms the one great difference between the mixing of coloured *lights* and the mixing of dyes and paints.

In mixing coloured lights the resultant hues produced have the combined brightness or luminosity of the constituents; while in mixing two dyes the result produced is much lower in brightness, because of the double absorption of coloured rays which the two colours have undergone.

For example, if violet and yellowish-green lights be combined, a white is produced, having the combined brightness of

Plate IV.

Showing how the Tertiary shades, Russet, Citrine and Slate, are simply the three Primaries, Red, Yellow and Blue, dulled with Grey.

[*See* CHAPTER V.]

both of these lights; while in dyeing and painting, by mixing violet with a greenish yellow a deep plum shade is produced; as the eye receives only those rays which have escaped the absorptive action of both the violet and the yellow green. In the former case the result of the mixture is brighter than either of its constituents; in the latter case it is duller than either, from its being largely mixed with grey due to absorption (see also § 43).

§ 46. In the dyed specimens to be found at the end of the book are several soft tertiary shades prepared by the admixture of the three dyestuffs—Victoria yellow, or orange, azo acid magenta, and indigo substitute blue. Where the orange is in excess, a shade of yellow brown, or old gold is produced, as at No. 10; but, if the blue be increased to form a greater proportion of grey, then a sadder or flatter shade is formed, *i.e.*, a dark rich brown as seen at No. 6. If the blue and yellow—producing a green—be in excess, then a sad green, or what is termed a sage, is the result, as at No. 11. It is seldom that two complementary dyestuffs—unless they be very strong and concentrated—can completely absorb all coloured rays when they are combined: yet in dyed pattern Plate I. we have a good example showing that when Victoria rubine and acid green are combined together, total absorption of light, or a black is produced, as shown in No. 3.

If the proportions of the three dyestuffs already mentioned, *i.e.*, Victoria yellow, azo magenta, and indigo blue substitute, be carefully adjusted so that neither of them predominate in the slightest degree to form a tertiary shade, then the result is a pure, neutral grey, such as we have at Nos. 7, 8, 9 of the dyed patterns. These are beautiful examples of neutral greys, produced by the careful combination of the three primaries. For the proportions of dyestuffs employed in dyeing each shade, see page 87.

§ 47. Before proceeding to study systematically the various phenomena produced by mixing colours, it may be well to say a few words concerning some important points in the correct use of colour terms. Much confusion often arises from the slack, indefinite way in which colours are sometimes described.

COLOUR CONSTANTS.

Colour Constants.—The first characteristics to be considered in relation to a colour are three in number—namely, *hue, purity, brightness*. These are generally termed its colour constants.

1. *Hue.*—The hue of a colour is that which is generally understood by the term *colour*, such as yellow, green, purple, blue, etc. The excessive predominance of one or two of the simple colours over the rest gives the hue to a colour, and the greater that predominance, the stronger will be the hue. This is really the first characteristic of a colour which demands our consideration, and from it we endeavour to *name* the colour. In mixing one colour with another the original colour must always predominate, otherwise it will become a hue of the colour which has been added. Thus in mixing red and blue together to produce violet or purple, if the red be in excess the result will be a violet of a *red hue;* but if the blue be in excess, then a violet a blue hue is produced. It is easy to remember the series of hues, when we bear in mind the various gradations of hue present in the spectrum or the rainbow, red, orange, yellow, green, blue and violet.

Thus it is more correct, in describing a reddish yellow, to speak of it as a yellow of a reddish hue than to say a yellow of a red *shade*, though this expression is very generally used in commerce and among dyers and colourists. The term *shade*, as we shall see presently, signifies in its correct

sense an admixture of grey or black. It is likewise better to describe reddish blues and violets as being of a red hue. It is wrong to employ the term *tint* instead of hue, as this term implies an admixture with white, or reduction. Thus we would not describe a greenish blue as a blue of a green tint, or a yellow of an orange hue as having an orange tint.

Cast.—This term is often employed to denote the distinctive hue of a colour. Thus we may describe a red as being of a bluish cast, or a blue having a green cast, meaning its prevailing tendency of hue.

2. *Purity.*—By the purity of a colour is meant its freedom from admixture with white light, or with any other colour. The purest colours, and therefore the standard of purity, are those of the spectrum obtained by passing sunlight through the prism, as represented in Fig. 2 (see § 16). When comparing ordinary colours, such as pigments or dyed materials, with certain portions of the spectrum, it will be found that though they correspond fairly well in hue to the spectrum colour, there is a want of depth and richness; which makes all such coloured objects appear pale before the pure colours of the spectrum. This is due to the quantity of white light reflected from the surface of all pigments and dyed materials. None of the ordinary colours can match the hues of the spectrum for purity. A pure colour is often termed *saturated.* But it must be remembered that a pure colour is not necessarily a bright or a rich colour, for there are some parts of the spectrum where the colours, which are perfectly pure, are not bright. Colours which appear pure to the eye may nevertheless reflect many differently coloured rays. We have already learned (§ 25) that naphthol yellow, for example, reflects not yellow rays merely, but a large number of red, orange and green. The beautiful aniline blues, which appear perhaps, quite pure to the un-

aided eye, reflect as a rule, a considerable amount of red, green and violet light. It is indeed very seldom that a pure, monochromatic colour is found, except when the colour solution is strong, or when dyed a deep, full colour on some rich-lustred fibre like silk. No ordinary pigment or dyestuff is perfectly pure coloured or monochromatic.

3. *Brightness or Luminosity.* This is the third colour constant, or feature of importance, in colour examination, and is distinguished by the total amount of light which is reflected from the colour to the eye. It is also described as the "clearness" of a colour. By various scientific methods it is possible to ascertain the relative degrees of luminosity possessed by the spectrum colours, and it is found that the most luminous colour is orange-yellow; while the least luminous—as might naturally be supposed—is violet. Between these two extremes there are all intermediate degrees of brightness. The following colours are (according to Prof. Rood) tabulated in a descending ratio of luminosity:—

1.	Orange yellow = most luminous	7,000
2.	Orange	6,000
3.	Greenish yellow to green	3,000
4.	Orange red	2,000
5.	Blue green, Cyan blue, Red (cherry) — Equal in luminosity	1,000
6.	Pure red, Blue — " "	400
7.	Ultramarine blue	90
8.	Dark red	80
9.	Blue violet	30
10.	Violet = least luminous	13

Having now considered the three distinguishing features of colour, or the constants, *i.e.*, (1) hue or colour proper; (2) purity, or freedom from white or other coloured light; and (3) brightness or luminosity, we may now consider the proper use of a few of the commoner colour terms.

§ 48. TINTS AND SHADES.

Tint.—The addition of white in regular quantities to a colour produces a *reduced* scale, or what are termed *tints*, of the normal hue. In dyeing or calico printing the admixture of white is, of course, an impossibility, but if the colours be dyed on a white material the gradual diminution of the quantity of the dyestuff equals the same thing.

It is said that 1 part of white light added to 360 parts of coloured light produces a very slightly paler tint that can be distinguished by the practised eye, and it is here that the skill of the experienced colourist is shown. An eye trained to distinguish the nicest variations in the hue or the tint of a colour can see decided differences in two colours which, to an ordinary person, appear as identical.

It is an important point to remember that in reducing a colour to form a good series of tints, there should be no variation in the hue of the colour. It is often noticed by textile colourists that in reducing certain colours into a scale of tints, the normal colour changes slightly in hue as it becomes weakened, thus giving to its lightest tint a slightly different cast of hue. In such a case it is often necessary to add a minute quantity of some other colour ingredient in order to maintain a regular gradation of hue.

For example, in reducing a red to form a salmon tint, it may be found to go off into too bluish a cast, and requires the addition of a slight touch of yellow to make it right. Yellows, in reducing into tints, often go off into a greenish cast or become buffy or reddish. Hence, it is often well for colourists and dyers to make trials in reducing their dyes to see how they go.

It is very seldom that in reducing blacks we get good greys, as some go purplish, others go reddish, while some reduce to a greenish tone, and hence it is necessary to add

some other colouring matter to neutralise this predominant hue and form a pure grey. The Chinese colourists have long been well aware of this, and the secret of their "Chinese ink" is that even when it is reduced with white to form the lightest tints it still preserves its fine neutral grey tone.

In reducing all classes of colours—yellows, greens, blues, etc.—to form tints, the colourist must often find that they require the aid of another colouring matter to keep them on the proper scale. The cause of this gradual difference in hue is owing to the natural impunity of all ordinary dyes and pigments and to the property of selective absorption, or dichroism, already considered in Chapter IV. (see § 39). For tints which harmonise or are complementary see Fig. 29.

Shades.—The addition of black in regular quantities to a colour produces a *darkened* scale, or what are termed *shades*, of the normal colour. The term "shade" in the ordinary colour nomenclature of commerce is greatly misapplied, and we hear it constantly used where the word *hue* is more correct. Thus a clear yellow is often described as a "pure *shade*" of yellow, which is a misuse of the word. A bright and pure hue cannot be correctly termed a "shade," which necessarily implies a greyness or dulness. The word shade is a very general one, and includes all the many tertiary hues, which are simply the primary and secondary colours flattened with grey or black, and all the variety of so-called mode or fashionable colours. These are sometimes described as "shades of tints".

The following are a few of the fundamental colours with their corresponding tints and shades :—

Fundamental colours.	Tints (admixture with white).	Shades (admixture with black).
Red (bluish) . . .	Pink.	Maroon.
Vermilion . . .	Yellow pink.	Russet.
Scarlet (orangy red) .	Salmon buff.	Brown.
Orange red . . .	Salmon buff (yellowish).	Yellow brown.
Orange	Salmon.	Terra cotta.
Yellow orange . .	Amber.	Yellowish terra cotta.
Orange yellow . .	Cream.	Old gold.
Yellow	Lemon or sulphur.	Citrine.
Yellow green . . .	Straw.	Olive.
Emerald green . .	Pea green.	Sage.
Bluish green . . .	Sea green.	Myrtle.
Turquoise . . .	Pale turquoise.	Dull indigo.
Colbalt, blue or indigo .	Pale blue.	Slate, to a deep navy blue.
Purplish blue . .	Azure.	Blue slate.
Mauve or bluish purple	Lavender.	Purply slate.
Violet	Amethyst or light violet.	Puce, or purplish black.
Reddish purple . .	Heliotrope.	Plum, or maroon.
Bluish red or crimson .	Pink (bluish).	Claret, or garnet.

For finding the various tints and shades which harmonise well with each other, or what are termed "complementary," consult Figs. 29 and 30.

The number of tertiary hues, with their tints and shades which can be produced by admixture is of endless variety, and we have only to examine the many beautiful pattern cards issued by the various colour manufacturing firms to realise the immense number of hues, all differing more or less from each other.

§ 49. **SCALE OF COLOUR.**—A scale is the collection or series of gradating tones of a given colour. There are as many scales as there are hues. Such a series of colours is sometimes termed "stepping" shades.

Besides the *reduced* scale of tints and the *darkened* scale of shades there is sometimes termed a dulled scale of broken tints, *i.e.*, normal hues mixed with progressive proportions of *grey*. These are generally termed "broken hues," and are merely dulled tones of the primaries and secondaries.

Tones. The series of gradations of a hue, weakened by the addition of white, or shaded by the addition of black, may

be termed tones of that colour, but they may also be described as tints and shades, as already given in § 48.

Sombre and sad colours are those belonging to the blue and violet class, and the broken tones of the luminous colours.

§ 50. **COMPLEMENTARY COLOURS.**—It has already been stated that certain pairs of coloured lights, when combined, produce white light. These colours are said to be complementary to each other. The following pairs of colours are complementaries :—

Red	and green blue.
Orange	,, deep blue.
Yellow	,, ultramarine blue.
Green yellow	,, violet.
Yellowish green	,, purple violet.
Green	,, red violet or purple.

With the Brewster or practical theory of primaries—red, yellow and blue—which the dyer and artist must adopt, the combination of two complementary hues produces grey or black, as the one colour absorbs all the rays of its complementary, and darkness is the result. It may be simply stated that the colour which is *absent* from a mixed colour is the complementary. Thus :—

Orange	(composed of	red and yellow)	is the	complementary	of	blue.
Green	(,,	yellow and blue)	,,	,,	,,	red.
Violet	(,,	blue and red)	,,	,,	,,	yellow.
Citrine	(,,	green and orange)	,,	,,	,,	violet.
Slate	(,,	green and violet	,,	,,	,,	orange.
Russet	(,,	violet and orange)	,,	,,	,,	green.

For a more extensive series of complementary hues see Figs. 29 and 30.

The complementary of a primary colour is therefore the secondary composed of the other two primaries.

A simple method of illustrating the primary, secondary and tertiary hues and their complementaries is seen in our coloured frontispiece, of which Fig. 27 is a diagram. In the

first are shown the three primaries, red, yellow and blue, combining to form the three secondary hues, orange, green and violet.

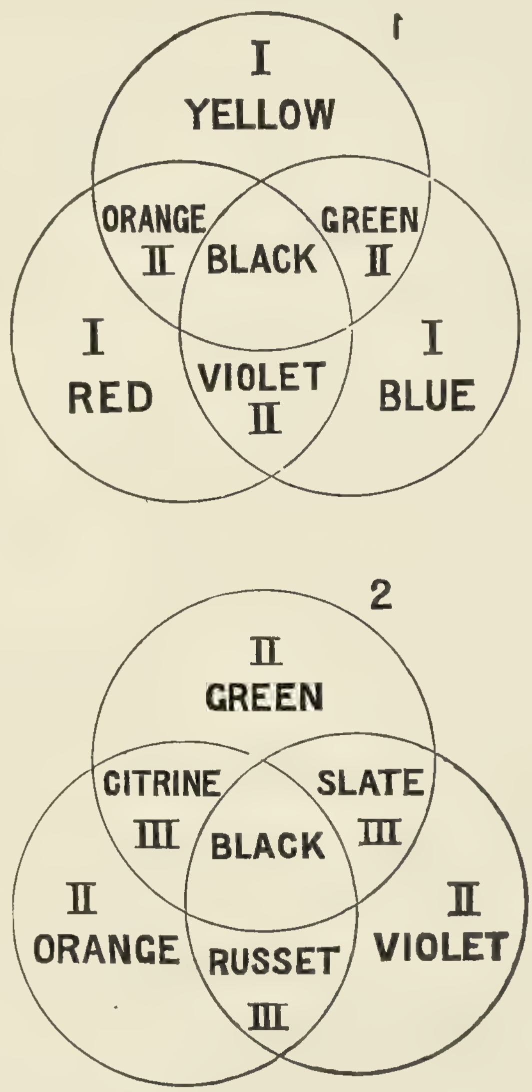


Fig. 27.—Diagrams showing the formation of secondary and tertiary colours from the three primaries red, yellow and blue. (See the coloured frontispiece, Plate I.)

In the coloured frontispiece it will be observed that—

Red and yellow	when combined	produce	orange,
Yellow and blue	,,	,,	green,
Blue and red	,,	,,	violet;

while the three primaries combined produce that absorption of all the coloured rays of light which represents black.

In this diagram the complementary colours are found opposite each other. Thus :—

Red is opposite to its complementary, green,				
Yellow	,,	,,	,,	violet,
Blue	,,	,,	,,	orange,

and *vice versâ*.

In the same manner the second diagram of frontispiece or of Fig. 27 illustrates the formation of the three tertiary shades by the combination of the secondaries, orange, green and violet.

Orange and green	produce	citrine.
Green and violet	,,	slate.
Violet and orange	,,	russet.

Orange is opposite its complementary, slate.				
Green	,,	,,	,,	russet.
Violet	,,	,,	,,	citrine.

In making pure tones of the secondary colours by the admixture of primaries, it is necessary to select those primaries *having a tendency of hue towards the desired secondary;* otherwise very poor and dull colours will be the result. To make a pure green, for example, the yellow and the blue must *not* be of a reddish cast, but be somewhat greenish in tone.

The presence of a little red along with yellow and blue produces a quantity of *grey*, which mars the purity and brightness of the green. This explains the reason why, in dyeing with a mixture of yellow and an alkali blue of a violet cast, a citrine shade is produced instead of a good green. But this subject, which is of the utmost importance to every dyer and colour mixer, is fully discussed in our next chapter on Colour Mixing. For the effects produced by mixing suitable and unsuitable primaries see coloured Plate V.

§ 51. A knowledge of the various complementary colours is of great importance to every dyer and colourist, as it enables

him to produce the finest effects of colour harmony and contrast. It is also of much service in studying the various phenomena observed in matching colours.

A ready method of finding the harmonising complementary of any given colour is found in the arrangement termed the "chromatic circle," which has already been introduced in Figs. 13 and 17. Though simple, it is a most convenient device for studying the chief varieties of colour and their mutual relations to each other. Fig. 28 represents the chromatic circle in its simplest form. At equal distances around the circumference are placed the three ordinary prim-

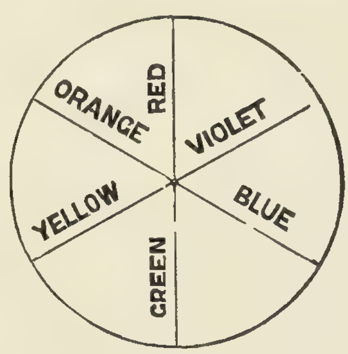


Fig. 28.—Chromatic circle.

aries — red, yellow, and blue — and their complementary secondaries—green, violet, and orange—are found exactly opposite them on the circumference. The colour at one end of any of the diameters is the complemetary to that found at the other end. A more extended chromatic circle is seen in Fig. 29, where sixteen different hues have been selected, forming eight pairs of complementaries. The inner circle represents the *tints* obtained from the various colours by reducing them with white.

In the table below is given the list of the corresponding complementaries which are found opposite each other in the outer chromatic circle :—

Pairs of Complementaries.

Scarlet carmine	and	emerald green.
Crimson	,,	yellowish green.
Violet or purple	,,	yellow.
Blue violet	,,	orange yellow.
Purplish blue	,,	yellowish orange.
Cobalt blue	,,	orange.
Turquoise	,,	orange red.
Blue green	,,	vermilion red.

In the same manner the complementary tints are as follows (see inner circle, Fig. 29) :—

Pairs of Complementaries (Tints).

Buff	and	pea green.
Pink	,,	straw.
Heliotrope violet	,,	lemon.
Lavender	,,	cream.
Azure	,,	amber.
Pale blue	,,	salmon.
Pale turquoise	,,	salmon buff
Sea green	,,	yellowish pink.

When these complementary colours or dyestuffs are combined, either on the palette, in the colour-tub, or in the dye-bath, darkness or a grey is produced. If the colours be sufficiently strong, a black will be the result. Owing to the natural impurities always present in ordinary colours, however, it is seldom that two dyes, unless in a concentrated state, produce a good black, as the slightest predominence of one of the colour constituents gives to the result a certain cast or hue which takes it from a pure grey or black.

Archil, which is of a deep claret hue, when combined with indigo extract, gives a good dense black, as the one colour totally absorbs the light of the other. Azorubine and acid green produce, when mixed, a fair black, and the beautiful pink of rhodamine, when combined with a yellow green, gives shades of bronzy grey. If the colouring matters be mixed in such a proportion that one colour predominates over another, then the mixed colour will have the hue of the

colour in excess. Thus, if scarlet and green be mixed so that an excess of green is used, a sage shade is produced; while, if the scarlet be the predominating colour, a brown or russet is the result.

In our next illustration, Fig. 30, we have a chromatic circle similar to Fig. 29; but the inner circle here repre-

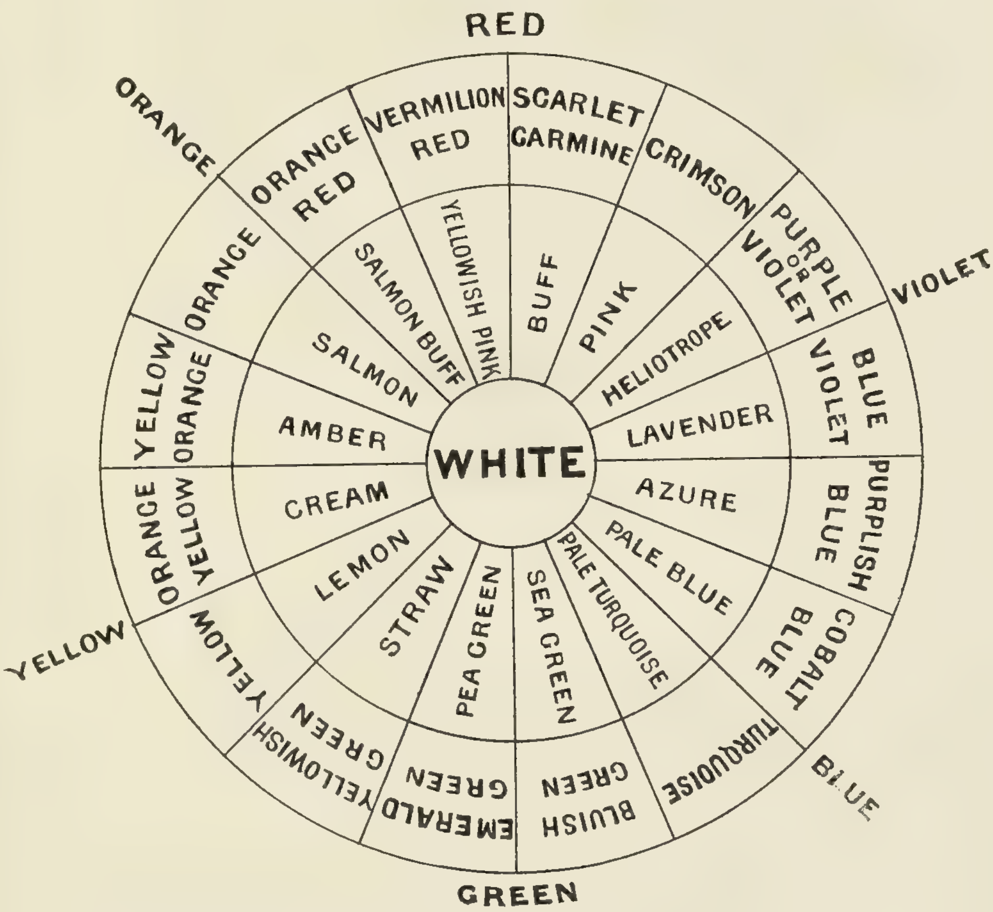


FIG. 29.—The inner circle represents the effects of adding white (tints) to the saturated colours named in the outer circle. The tints opposite each other are complementaries.

sents the effect produced by combining the complementaries named at the opposite side of the outer circle.

It will be observed that all these tertiary hues are, as we have already learned (see § 45), merely primary and secondary colours saddened with varying proportions of grey or black.

The results of the mixing of the two complementaries may be represented in the following table, in which the colour which predominates in the mixture is printed in larger type.

Thus **scarlet carmine** + emerald green = brown, may be taken to represent that a mixture of scarlet and green, with

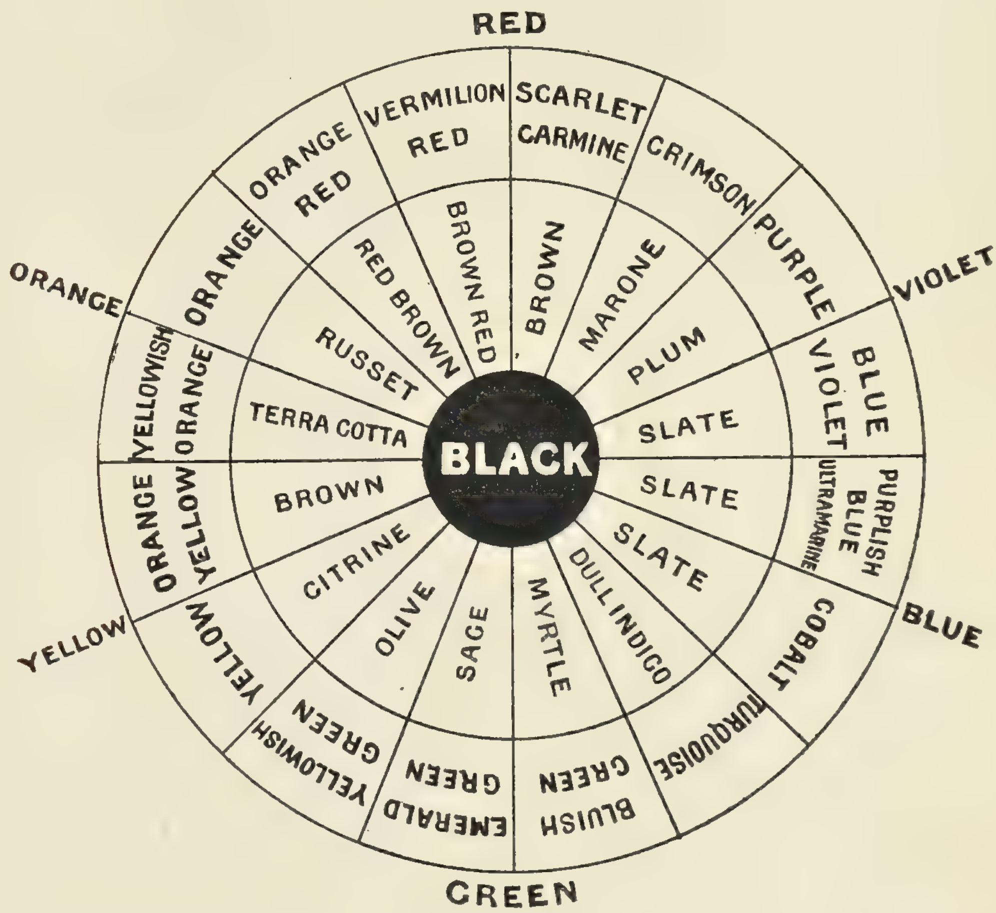


FIG. 30.—The inner circle represents the effect produced by combining the complementaries named at the opposite sides of the outer ring. They are shades of the normal colours, similar to those produced by the addition of grey or black.

scarlet in excess, produces a brown; while scarlet carmine + **emerald green** = sage colour, means an excess of green gives to the mixture a sage hue. The following list of colours. obtained by admixture, will be found in the chromatic circle, Fig. 30.

The mixed hues in the inner circle are complementary

to their opposites in a similar manner to the outer colours already described.

Shades produced by admixture of complementaries.

Colour in excess.		Colour deficient.		Result of admixture.
Crimson	+	Yellow green	=	Maroon.
Yellow green	+	Crimson	=	Olive.
Purple	+	Yellow	=	Plum.
Yellow	+	Purple	=	Citrine or olive.
Blue	+	Orange	=	Slate.
Orange	+	Blue	=	Russet.
Turquoise	+	Orange red	=	Dull indigo.
Orange red	+	Turquoise	=	Red brown.
Blue green	+	Vermilion red	=	Myrtle green.
Vermilion red	+	Blue green	=	Brown red.

This brings us now to the important subject of colour mixing, to be studied in the next chapter.

6

CHAPTER VI.

COLOUR MIXING.

MIXING QUALITIES OF COLOURS—PURE AND IMPURE GREEN, ORANGE AND VIOLET—LARGE VARIETY OF SHADES FROM FEW COLOURS—CONSIDERATION OF THE PRACTICAL PRIMARIES, RED, YELLOW, BLUE.

§ 52. One of the first duties of the colour chemist and the dyer when testing a colouring matter is to examine, what we might term, its mixing qualities, and learn if it is suitable for producing good colours by admixture with others. It is well known to colour mixers that two apparently similar blues, when mixed with equal proportions of yellow, may give two greens of a very different cast. Some reds and yellows are better fitted for giving a pure, good orange than others; and likewise some blues and reds give very poor violets compared with others. This is a most important consideration to the colour mixer, when he mixes his shades to produce a certain desired effect.

The coloured plate (V.) illustrates the different results obtained by mixing suitable and unsuitable colours.

In making a green from blue and yellow it must be remembered that neither of these component colours must contain any of the third primary red, as its presence gives rise to a corresponding absorption of the green rays—producing an amount of grey which dulls the green colour.

Green. Thus No. 1 (Plate V.) shows how a slightly reddish blue, like some of the alkali blues, azure or ultra-

Plate V.

Fig. 1.

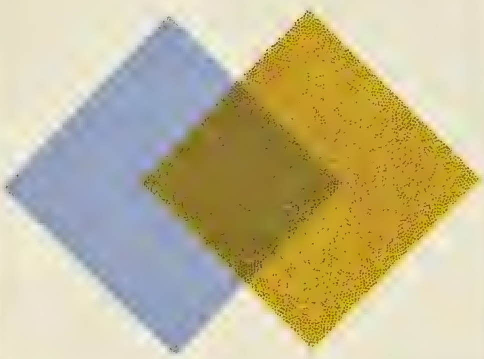


Fig. 2.

Fig. 3.

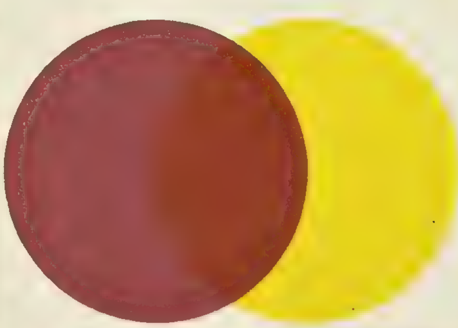


Fig. 4.

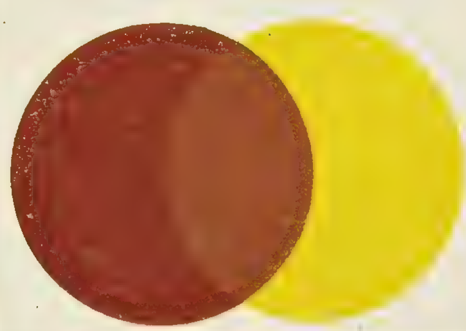


Fig. 5.

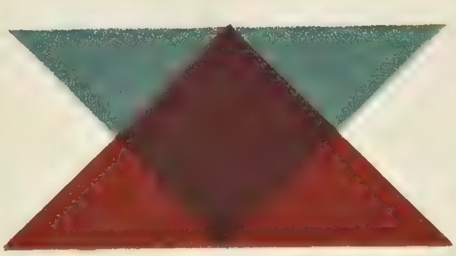
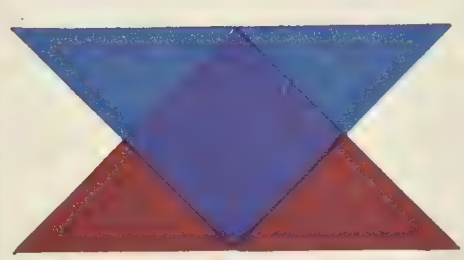


Fig. 6.



Showing how the purity and brilliancy of mixed Colours depend upon the suitability of their Component Colours.

[*See* Chapter VI.]

marine blues, the reddish brands of Victoria blue, etc., when combined with a yellow, does not produce a bright green, but a green having a large amount of grey—namely, a citrine. If the yellow be of an orange cast, the effect is still greater.

This same citrine shade can be reproduced by adding to a pure bright tone of green a small proportion of red or of grey. Yellows of an orange cast, such as Indian yellow, Victoria, fast yellow, etc., and those of the buttercup hue cannot therefore be used for making good greens by admixture.

In this example of No. 1, where both the blue and the yellow tend to be reddish, the effect is of course exaggerated; but pure bright greens can never be obtained by mixing a yellow and blue which show a trace of red.

No. 2 shows the brilliant green made by combining a greenish blue like cyanine blue, wool green, acid green, etc., with a clear greenish yellow like chinoline, picric acid, or naphthol yellows. A superb parrot green of great brilliancy can be dyed with naphthol yellow and night blue, which is of a greenish cast. In pattern Plate II. at the end of the book, is shown a beautiful olive shade No. 5, dyed with Victoria yellow and indigo substitute. As the yellow and the blue are both of a reddish tone, a very sad green, or citrine, is the result of their combination.

Orange.—In the same way, in order to produce a pure tone of orange, neither the constituent red, nor the yellow must have a bluish cast; otherwise a poor, muddy orange will be the result of their combination.

No. 3 (Plate V.) shows the combination of a bluish red like magenta, azo rubine, azo carmine, etc., with a yellow, producing, instead of an orange, a dull russet hue. This is owing, as we have already stated, to the fact that the presence of the third primary (in this case blue) produces

a proportion of grey, which changes the pure orange into a broken tone.

Exactly the same colour is obtained by adding a slight quantity of blue or of grey to a pure tone of orange.

No. 4 shows the production of a pure orange by combining a yellowish red or scarlet with a yellow devoid of any green cast. There being no third primary present no absorption of the orange takes place, which means that no grey is present to destroy the purity of the orange.

The purest tones of orange are found in the aniline azo oranges, of which there is a large variety. They are pure and unmixed colours (*homogeneous*), and give a clearer and better tone of orange than we can get by admixture.

Violet.—Nos. 5 and 6 show the production of good and poor violets by the admixture of the different qualities of red and blue. To obtain a full beautiful violet these two constituent colours should both tend toward the bluish cast. The result is a violet free from any appearance of grey (see No. 6).

Bluish reds, such as azo rubine, carmine, magenta, when mixed with the reddish-toned alkali blues, produce very good violets.

Where a scarlet red and a greenish blue are combined, as in No. 5, a poor dull violet is the result. The presence of the yellow primary in the scarlet red produces absorption of the pure violet, and gives to the resultant violet a greyish dull effect.

Wool scarlet and cyanine, or patent blue, for example, give very poor violets by admixture.

The purest tones of violet are obtained from the aniline colours, like Hofmann's violet, methyl or ethyl violets, etc. These are pure and homogeneous colours, and not produced by any admixture of red and blue.

The above are a few simple examples selected from many

others which might have been given had space permitted us; but they are sufficient to show that when colours are mixed, the character of the resulting colour depends upon that of its constituent colours: also that when a certain colour effect is desired it is necessary to pay due attention to the properties of the individual colours constituting the mixture. The purity of a compound colour depends upon the suitability of its constituent colours.

§ 53. In studying the art of colour mixing, one of the most astonishing features which strikes us is the wonderful variety of different hues which can be obtained by the combination of only two or three fundamental colours. Although, at the present day there are thousands of different dyestuffs, all differing from each other in colour and chemical properties, the skilled colour mixer requires only a few carefully selected colours to produce as wide a variety of effect as he desires. By knowing thoroughly the mixing or combining capabilities of his dyes, he may produce, with three simple dyestuffs, over fifty or more different shades by simply varying the proportions of the three fundamental colours.

This fact may be readily observed in examining the many beautiful pattern cards issued by the various colour firms, where we find that a splendid selection of fifty or sixty shades, varying widely in appearance, can be obtained from two or three simple dyestuffs. For example, from azo-acid magenta, an aniline blue, like patent blue N., and a yellow, like azo yellow, can readily be obtained fifty quite distinct shades; and from each of these shades may be made a series of four stepping shades or reduced tints, gradating from the dark colour to its light tint, so that no less than 200 distinct shades can be made from these three simple dyestuffs. Between the four stepping shades of a series the experienced colourist can distinguish many other intermediate ones, so

that the 200 could be subdivided into three or four hundred different shades.

A scale or gradating series of shades, from a deep, full shade to a light tint of the same colour, is, of course, produced by varying the proportions of the dyestuffs used.

Thus, for 100 lb. of wool:—

(1)	150 grams	azo acid magenta	dyes	= a delicate tint of heliotrope.
	25 ,,	patent blue		
(2)	300 ,,	magenta	,,	= a medium shade of heliotrope, a full step deeper than No. 1.
	50 ,,	patent blue		
(3)	600 ,,	magenta	,,	= a deep full purple, a full step from No. 2.
	100 ,,	patent blue		

The three above shades, light, medium and strong, form a beautiful gradating series of heliotrope shades.

By altering the proportions of either blue or red a predominating red or blue shade is obtained.

Thus:—

750 grams patent blue
400 ,, azo magenta } gives a deep indigo blue.

while—

100 grams patent blue
300 ,, magenta } gives a deep claret red or maroon.

In the following table we have the proportions of a few simple dyestuffs which produce in dyeing a wide range of useful shades.

Solid Blue.		Orange G.		Azo Carmine.		Colour obtained by Combination.
0·45	+	3·5	+	2	=	Red brown.
0·35	+	3·5	+	0·1	=	Olive brown.
0·01	+	0·05	+	0·05	=	Pale salmon.
0·15	+	0·15	+	0·15	=	Pale plum.
0·15	+	2·5	+	0·2	=	Golden brown.
1	+	0·5	+	1·5	=	Violet black.
1·2	+	0·21	+	0·24	=	Red plum.

From patent blue, azo acid magenta, and azo yellow we obtain even a wider range of shades. The weights of colour-stuffs here given (grams) are for dyeing 100 lb. of wool.

Patent Blue.		Azo Acid Magenta.		Azo Yellow.		Result of Mixture.
60 (grams)	+	30 (grams)	+	20 (grams)	=	Light slate grey.
100 ,,	+	300 ,,	+	300 ,,	=	Cinnamon brown.
500 ,,	+	220 ,,	+	60 ,,	=	Dark blue grey.
20 ,,	+	30 ,,	+	100 ,,	=	Delicate olive shade.
400 ,,	+	400 ,,	+	100 ,,	=	Dull purple.
50 ,,	+	150 ,,	+	110 ,,	=	Brown drab tint.
25 ,,	+	5 ,,	+	250 ,,	=	Light yellow green.
75 ,,	+	15 ,,	+	509 ,,	=	Bright leaf green.
225 ,,	+	45 ,,	+	1 ,,	=	Deep olive.
25 ,,	+	150 ,,	+	... ,,	=	Heliotrope.
100 ,,	+	600 ,,	+	... ,,	=	Rich purple.
100 ,,	+	35 ,,	+	50 ,,	=	Delicate sea green.
100 ,,	+	100 ,,	+	100 ,,	=	Soft grey.
400 ,,	+	450 ,,	+	400 ,,	=	Dark grey sage.
400 ,,	+	150 ,,	+	400 ,,	=	Beautiful olive.
30 ,,	+	23 ,,	+	... ,,	=	Delicate dove grey.
40 ,,	+	15 ,,	+	500 ,,	=	Rich yellow olive.

In the dyed pattern Plates II., III., IV., at the end of the book, we have a few beautiful soft shades produced from Victoria yellow, indigo substitute, and azo acid magenta. Thus :—

Plate.	No.	Shade.	Dyed with: Victoria Yellow.	Dyed with: Indigo Substitute.	Dyed with: Azo Acid Magenta.
II.	5	Olive	400 grams	100 grams	
,,	6	Rich brown	2 kilo, 200 grams	200 ,,	200 grams.
III.	7	Soft grey	22 grams	162 ,,	62 ,,
,,	8	Mid grey	50 ,,	325 ,,	125 ,,
,,	9	Dark grey	100 ,,	650 ,,	250 ,,
IV.	11	Sage Green	200 ,,	250 ,,	50 ,,
,,	10	Yellow brown	200 ,,	90 ,,	(Orange) 600 grams.

We are now in a position to study intelligently the various absorption phenomena observed during the mixing of ordinary colours and dyes; and, in order to do so systematically, we had better consider them briefly in the following order :—

1st. Primaries: red, yellow, blue.

2nd. Secondary colours: orange, green, purple or violet.

3rd. The large variety of hues termed the tertiaries, or sad shades.

PRACTICAL PRIMARIES. RED, YELLOW, BLUE.

§ 54. **Reds.**

At the present day there is a large variety of red colouring matters at the command of the dyer and calico printer, ranging from bluish reds, such as roccelline and azo rubine to orange reds and scarlets. The pure red of the spectrum lies in the locality of the Fraunhofer lines, A, B, C (see Fig 7). Clerk Maxwell selects his sensation of pure red even beyond the line C towards D. Mercuric iodide is sometimes taken as a type of normal red, but it, unfortunately, changes its hue on exposure to light.

Many of the coal tar reds, such as the various brands of scarlet, 3 R. to 6 R., palatine, brilliant and wool scarlets, when used in sufficient strength to dye a good saturated colour, represents a fair monochromatic scarlet red. Cochineal red dyed with cochineal, oxalic acid, and tin crystals, also gives a good bright scarlet.

Any of the above-mentioned aniline reds dyed at the proportion of 3 lb. of colour to 100 lb. wool or cashmere cloth, will produce a splendid red, which, on examination with the pocket spectroscope (see Chap. III.), will be found to consist of red rays from the locality of the spectrum, marked with the lines A, B and C. A bluish class of reds, much stronger than the scarlets, are the fast reds or roccellines, of which there is a large variety sold under various different commercial names, such as rubidin, azo rubine, carmoisin, claret red, amaranth, etc., etc.

By viewing a solution of an aniline scarlet with the spectroscope, it is found to transmit almost a pure red, giving a spectrum similar to that of ruby glass, as seen in the illustration (Fig. 18).

§ 55. SCARLETS may be described as orange reds, *i.e.*, reds having no bluish cast. We can never speak of a scarlet of a *bluish* hue, as scarlet denotes a predominance of orange or yellow.

The locality of scarlet on the spectrum is about C½ D, or midway between the lines C in red and D in yellow.

The word vermilion now denotes a scarlet red, but, in its old original meaning, it was more of a crimson hue, like a rose. For example, Spenser speaks of the "Vermeill red like roses".[1] Vermilion is derived from the Latin *vermes*, a worm, and originally designated the *kermes* insect or cochineal, from which we derive the words *crimson* and *carmine*: so that vermilion and crimson, though now considered quite different hues of red, were evidently the very same colour originally. To the colourist the subject of colour nomenclature forms a most interesting study.

Formation of Scarlets. An interesting method of producing reds and scarlets by admixture is by combining rhodamine pink and an aniline yellow, such as tartrazine or naphthol yellow, or the eosines with some of the azo oranges. Rhodamine and yellow, when mixed together in suitable proportion, give a fine scarlet. This is owing to the yellow absorbing the violet rays transmitted by the rhodamine pink, which leaves only the red and orange to be freely transmitted. This gives the sensation of a fine scarlet colour.

This may be readily seen by examining the absorption spectra of the two dyes (Fig. 31). Thus (A) represents the absorption band of rhodamine, the shaded portion representing the locality in the spectrum where the coloured rays are absorbed. It shows that red, orange, and orange yellow are transmitted, and also the blue, blue violet, and violet; while the yellow, yellow green, and green are absorbed,

[1] "Like a rose in vermeil tint."—KEATS.

i.e., the shaded portion from C½ D to F in the blue green. Naphthol yellow, (B) on examination with the spectroscope, is found to absorb all the violet end of the spectrum. When rhodamine pink and yellow are combined, therefore, there is complete absorption from the extreme violet, through blue, green, and yellow, as far as orange; this leaves only the red and red-orange rays, A, B, C, to be transmitted, as seen in C, Fig. 31. This explains the production of reds and scarlets by the mixing of eosine pinks with orange or yellows. For an example exactly the opposite in effect, namely, where the *red* end of the spectrum of

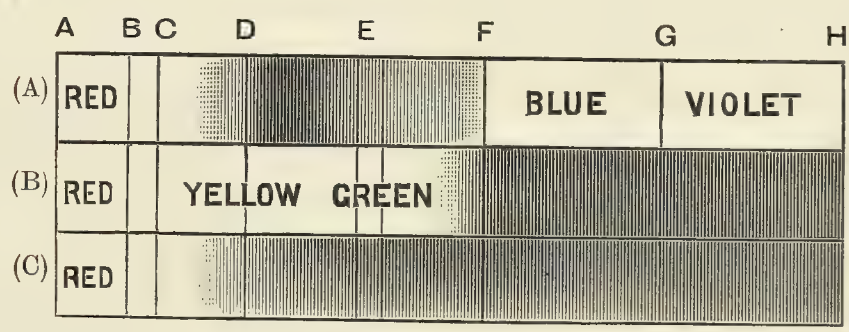


FIG. 31.—Showing the formation of a red by the combination of rhodamine (A) and naphthol yellow (B). The combined spectra (C) show transmission of the extreme red rays only.

rhodamine is absorbed, leaving the violet and blue rays untouched, see the formation of a violet in § 66, Fig. 36.

Among sheepskin-rug dyers where a boiling temperature cannot be employed to fully develop the aniline scarlet dyes, a very good red, ranging from a bluish tone to that of a scarlet, is made by combining acid magenta and picric acid. This dyes at a low temperature suitable for the skin dyer. The formation of this red is exactly similar to that already given with rhodamine pink. The acid magenta being a blue red, reflects not only red but blue, violet blue, and violet. This may be represented by the simple chromatic circle (Fig. 32).

The picric acid being a yellow, transmits red, orange,

yellow, and green, and absorbs the remainder of the spectrum (see 2).

Hence, when these two dyes are combined, as at 3 (Fig. 32), all the rays are absorbed except the red.

If the yellow be predominant a scarlet red is produced, and if the magenta be in excess a bluish tone of red is obtained.

The same scarlet colour is obtained either from an orange or a yellow; it does not matter which is used, as their only function is to absorb the violet end of the spectrum, the rhodamine itself absorbing sufficiently far towards the orange [see (A Fig.) 31].

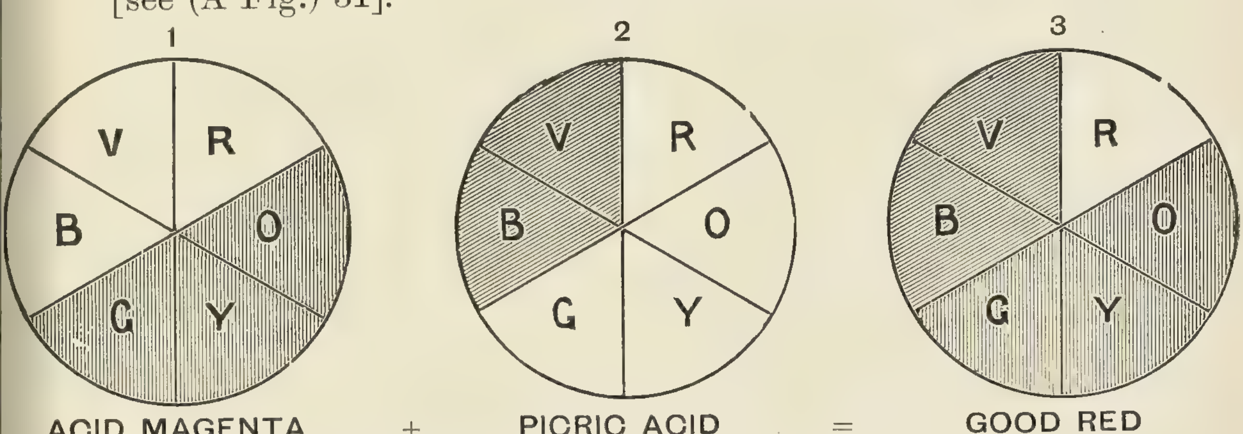


FIG. 32.—Showing the formation of a red by the combination of magenta and picric acid.

The formation of a scarlet in this case is not simply a mixture of red and yellow making an orange red, but is the result of the shutting off, or absorption of, the blue and violet end of the spectrum of rhodamine, leaving the only remaining rays at the red end of the spectrum to be reflected.

For an example of absorption exactly the opposite to this see the production of a violet by the mixture of green and rhodamine pink (see under the Violets). In the case of the scarlet, the red is transmitted and the violet end of spectrum absorbed; while in the formation of a violet, the red end of the spectrum is absorbed and the violet end transmitted.

§ 56. Bluish Reds.—Crimson, claret, magenta, cardinal, amaranth, garnet, etc., etc., denote red colouring matters of a bluish hue. Some of the aniline dyes of this nature, such as magenta (a salt of rosaniline) and rhodamine possess a purity and luminosity which far exceeds any bluish red obtained by admixture.

The term purple is generally applied to a very red blue or a red violet, which can be made by mixing Perkin's mauve with magenta. Purple, however, belongs more to the violet class of hues, and will be considered under the Violets, § 64.

The number of tones of red which can be made by the dyer and colour mixer is infinite, as they range from scarlets or yellow reds to blue reds or crimsons and purples; and their dull shades range from claret to maroon and puce.

§ 57. Pinks.—The beautiful class of rose colours known as pinks are diluted crimsons, or bluish reds. The most brilliant pinks are those derived from the aniline colours, the eosines, of which there is a large variety, and known under the names, rosebengal erythrosine, phloxine, rhodamine rosazeine, methyl eosine, etc. Before the introduction of these coal tar pinks there was no other dye to compare with them for brightness and purity of hue. Indeed, when they are unmixed they are so brilliant that they must be used very sparingly in textile colouring. Silk and cashmere, when dyed with 1 to 2 per cent. of rhodamine B., is perfectly dazzling in its brightness of hue. When examining such colours the eye readily becomes fatigued, so that the colourist is unable to make an accurate judgment of the hues. To enable him to examine such bright colours with comfort he must resort to the use of glasses slightly tinted with green or blue, when they assume the appearance of soft violets and purples, which can be carefully compared and examined with leisure. The absorption spectrum of these pinks, as seen

in Fig. 22 (No. 1) and Fig. 24, is very sharp and decided. Where the absorption band of a colour is narrow and intense, the result is a pure and luminous colour. When mixed with other colours, greater absorption is produced, which tends, more or less, to make the resultant colour dull or less luminous.

When a yellowish green, such as wool green or acid green, is combined with rhodamine pink, a black or grey is produced, due to the total absorption of all the coloured rays.

A beautiful series of delicate tints of mauve, heliotrope and violet are obtained by the admixture of eosine pinks and some of the bluish aniline greens, like wool green, malachite, Victoria or brilliant greens. The manner in which these are formed is the same as the violets (*q.v.*).

§ 58. Tints of Red.—When reds are reduced either with water, as in the dye-bath, or with paste, as in calico printing, to form a series of tints, it is found that some go off bluish, while others reduce to a yellowish or buffy cast, and therefore require the addition of another colour to keep them on the right scale. Thus, if a series of reds gradating into pinks are to be made from some of the aniline reds, it is often necessary, in the third or fourth reduced tint, to add a small quantity of a bluish pink to keep the series in harmony, if the red has a tendency to go yellowish. Many similar slight changes in hue are observed when reducing colouring matters to form a class of tints. This arises from the slight dichroic properties, or what is termed selective absorption, naturally present in nearly all dyes. For the cause of this dichroism see § 39, Chapter IV. Tints of a bluish red are termed pinks, while those of an orange red or a scarlet are termed salmon, buff and flesh colours. *Shades* of red, *i.e.*, red mixed with black, form the class of colours termed claret, maroon, puce, etc.

§ 59. Yellow.

It is a matter of some difficulty to locate exactly on the spectrum where the perfect representations of the various standard colours are to be found.

The locality assigned to yellow is generally a little beyond the Sodium line D, more towards the green-yellow portion of the spectrum. The D line is in the midst of the orange yellow (see Fig. 7).

Yellow is one of the important colours to the colourist; not simply because of its great brilliancy or luminosity, but because of its somewhat unique position in regard to the true theory of colour. As we have already stated, all dyers and colourists must accept the red, yellow and blue theory of primary colours (Brewster theory) as the only applicable standard where ordinary dye colour stuffs are employed. We cannot produce a yellow by admixture of other colours, hence we call it a primary; but with the physicist, who employs the Young-Helmholtz theory, yellow is considered a secondary colour, as it can be produced by the combination of red and green lights (see Plate III., No. 1).

Yellows are found to range from those of a greenish cast to an orange yellow; but those belonging to the former class, *i.e.*, greenish or lemon-toned yellows, are considered the finest. Among the beautiful yellows of this description may be mentioned auramine, picric acid, quinoline or chinoline, naphthol and tartrazine yellows. The beautiful, clear, greenish cast of the two latter dyes becomes evident when they are diluted. In their strong tones they are pure golden yellows.

Two yellows in their deep tones may match each other perfectly; but when diluted to form light tints of yellow, may give altogether different results: one tint may be of a greenish hue, while the other may have a reddish or buffy cast. This is owing, as we have already learned, to the property of

selective absorption, or dichroism (see § 39) present in all dyes.

Yellows of a greenish tone make the purest and most brilliant greens by admixture with greenish blues. A bright green of superb quality may be dyed on silk or wool with three parts quinoline and two parts Victoria, malachite or brilliant greens. Such a green keeps its vivid beauty even in artificial light.

Yellows of this greenish cast lose much of their beauty in a yellow light, and become pale and ineffective. If they are of a light tint, they cannot be distinguished from white.

Yellows, to look well in gas or lamplight, must belong to the orange or buttercup class of hue.

When yellow is mixed with a suitable proportion of pure grey, a soft, olive-green shade is produced, which, to the inexperienced colourist, appears as if it had been mixed with a quantity of green or blue.

Beautiful shades of olive and citrine are produced in this manner, which shows that they are simply dulled yellows, *i.e.*, yellows having a quantity of grey in their composition, as already observed when studying the formulæ of these tertiary shades in § 45.

Olives dyed in this simple way match those dyed with a mixture of orange, yellow and green or blue.

Several brands of aniline yellows have a reddish cast, or what might be termed buffy yellows, like azo flavine S., R., 2 R., etc., orange N., metanil, fast and brilliant yellows, etc. Such tones of yellow are suitable for making dull sage greens or citrines by admixture; but they are too red to give clear, brilliant greens. This may be seen in Plate V., Nos. 1 and 2, and also in the dyed shade, No. 5, on pattern sheet 2 at the end of the book, where Victoria yellow and indigo substitute are combined.

The spectroscopic examination of a yellow—no matter

how pure it may appear to the eye—affords a very good example, showing the compound nature of all our ordinary colours, like paints and dyes. Only the yellow of the spectrum consists of pure or homogeneous yellow light. A solution of naphthol yellow in water, or a piece of silk dyed with this dye, presents to the eye the impression of a pure yellow. But if we examine the yellow with the spectroscope, as described in Chap. III. (§ 24), we find that it contains not only yellow, but red, orange, green and bluish green, while the blue and violet rays are totally absorbed.

But the red and green and the orange and green blue are in such proportions that they combine to form *white* light within the eye; so that the yellow we perceive is composed of the yellow part of the spectrum mixed with a proportion of recombined white light.

We have already learned that the true interpretation of the green colour produced by mixing yellow and blue together is that the blue absorbs the red and yellow reflected by the yellow; while the yellow absorbs the blue and violet reflected by the blue, leaving only the green rays *unabsorbed* to produce the result.

Yellow, when mixed with black or grey, produces *shades* of olive or citrine. Beautiful shades of olive can be dyed by simply employing two colours, *i.e.*, an aniline grey and a yellow, such as naphthol yellow. This is an instructive dyeing experiment, as the shades produced appear to be much greener than what is usually expected from the combination of a grey and a yellow.

§ 60. Blue.

As blues vary greatly in tone, from greenish blues to reddish blues, it is somewhat difficult to assign accurately the exact position on the spectrum of a typical blue.

A beautiful greenish blue, which is termed cyan blue, is

found about the fixed line F on the spectrum; while a pure azure blue lies between the lines F and G (*i.e.*, F½, G) (see Fig. 7). At the line G the blue is of a strong violet hue.

Blue is a primary colour of the Young-Helmholtz theory as well as the practical (Brewster) theory. Genuine ultramarine made from lapis-lazuli is generally taken as the standard of a pure normal blue, and in some of the finer aniline blues, such as Victoria blue, night blue and the alkali blues, 6 B, may be found a fair representative of the beautiful spectrum blue.

The various brands of blue now at the command of the dyer and colourist, are almost unlimited since the introduction of the coal tar colours; but, before the aniline blues were known, the dyer depended solely on a few natural blue dyes such as indigo, woad and Prussian blue.

There are several beautiful greenish blues, derivations of aniline, which are much used for dyeing bright greens, peacock blues, etc. Owing to their free transmission of the pure green rays and the absorption of the red and orange in their spectra, they produce, by admixture with yellow, very luminous greens. Turquoise, methyl blue, cyanine patent blue, N., and others may be given as examples of pure greenish blues. Such look well in artificial light, as they keep their clear blue appearance, and do not become dull and flat like the azure blues.

In commerce the various brands of blues are designated by letters, such as B., 2 B., etc., up to 6 B., which is the finest and purest tone of blue made, while the reddish blues are characterised by the letters R., 2 R., etc., according to their degree of redness of tone.

In reference to the aniline blues and other colours it may be remarked that those which are sometimes termed the "1st Kettle" are the best and purest products, while those

of the 2nd or 3rd Kettle are not so pure, containing as they do more or less of the dissolved impurities.

Indigo blue is often mentioned as one of the seven fundamental colours of the spectrum lying between the green and blue about the line F, but this colour term is now falling into disuse, as no colour, corresponding to indigo, is present in the solar spectrum. It is more correctly termed *cyan blue* instead of indigo.

Many blues of a greenish cast, such as glacier blue, helvetia, patent blue, cyanine, and cyanol are very useful dyes to the calico printer and dyer, not only on account of their dyeing level shades, but because they mix readily with other colours to produce useful compound shades. They are much used for giving fine tones of olive, old gold, citrine, russet, etc., with red and orange.

Such blues as we have already seen (Plate V., Nos. 1 and 2) are the best for producing clear and brilliant tones of green by admixture with yellow. This is owing to their absence of a red or violet cast.

If a blue shows a strong tendency to transmit the red rays of the spectrum it is possible to combine it with a yellow and produce, not a *green*, but a dull *red* or claret colour.

Take a solution of litmus, for example, which is a blue colour, transmitting the red rays more readily than the green and blue. By viewing a moderately deep blue solution of litmus through a yellow-tinted glass or film, we do not get a green as might be expected, but a purply *red* colour.

§ 61. A fairly good blue can be made by combining green and violet together; such compound blues are sometimes known as "indigo substitutes" (see also § 33). The formation of this compound blue can readily be understood by resorting again to the simple chromatic circle method of examination.

Take, for example, the two dyestuffs malachite green

and methyl violet, which when combined in suitable proportion give a very good blue (see the dyed pattern No. 4 at end of the book).

Fig. 33, No. 1, represents the chromatic analysis of the colour given by malachite green, and shows the absorption of the red, orange, and violet rays, with transmission of yellow, yellow green, green, blue, and cyan blue.

No. 2 shows the absorption of methyl violet, *i.e.*, the orange, yellow, and yellow-green rays, while the red, and from the green to the violet, are all freely transmitted.

When those two dyestuffs are combined as shown in No. 3 the only coloured rays which are not absorbed are the

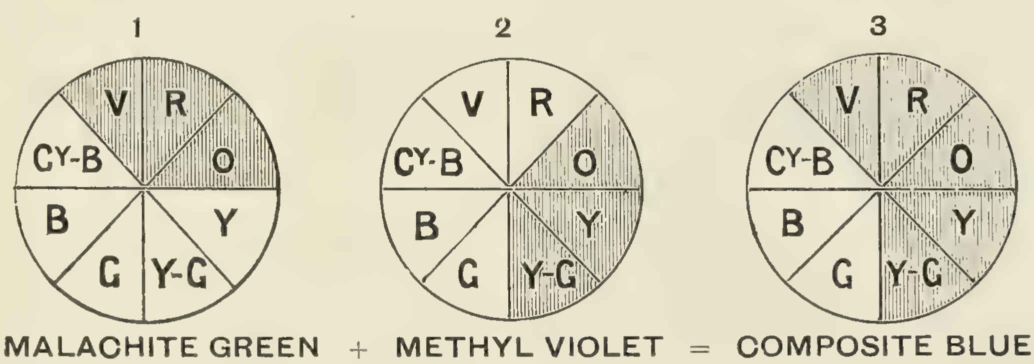


FIG. 33.—Simple chromatic circles showing the formation of a *blue* by the combination of malachite green and methyl violet.

cyan blue, blue and green. These combine on the retina of the eye to give the sensation of the blue; hence the origin of the blue colour by the mixture of green and violet. This may also be represented by the absorption curve, as in Fig. 34, instead of the chromatic circle. If we examine such a composite blue with the spectroscope, we shall find the brightest part of the spectrum *i.e.*, orange red, orange, yellow, and yellow green, is more or less absorbed, while the green and blue of the spectrum is freely transmitted.

The benzaldehyde greens, like Victoria and malachite, transmit a certain amount of red which gives to the compound blue a violet cast, but if a purer green be employed,

showing total absorption in the red, a much purer blue will be obtained by admixture.

(A) represents the absorption spectrum of malachite green, showing strong absorption in the orange red at C. (B) is spectrum of methyl violet, showing strongest absorption in the yellow at D. (C) gives the absorption curve of a composite blue (A and B mixed), showing the transmission only of a green and blue, with a little extreme red (see the dyed specimen No. 4 at the end of the book).

Blues change greatly in appearance in an artificial light, especially if they belong to the deep azure or violet cast. Pure greenish blues look well in gaslight; but those having

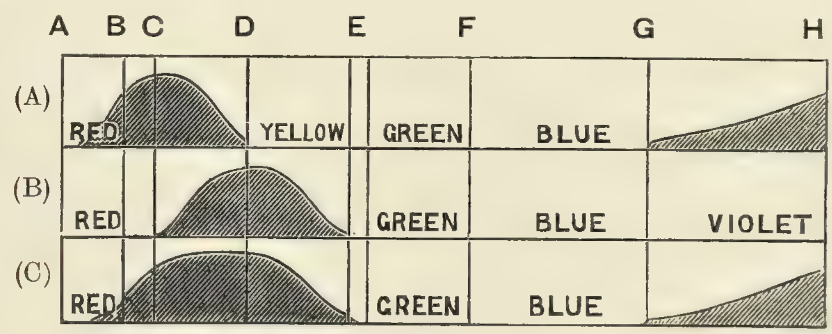


Fig. 34.—Absorption spectra of (A) malachite green, (B) methyl violet, (C) composite blue produced by combination of (A) and (B).

the slightest tendency towards a violet hue appear much redder and duller. Deep navy blues appear almost blacks in ordinary gaslight, from the deficiency of blue rays in that illuminant. For the aspect and behaviour of the various colours under artificial lights, the reader may consult our companion volume on *Colour Matching on Textiles*.

When red and blue are combined, violet is produced, as we have already seen in No. 6 of Plate V.; and also in the frontispiece. A scarlet red does not produce a good violet; the red must tend to the bluish or crimson hue. Blues, when mixed with proportions of grey or black, produce various shades of bluish greys or *slates*, and, when reduced with white, give delicate tints of pale blue.

CHAPTER VII.

SECONDARY COLOURS — ORANGE — GREEN — VIOLET — NOMENCLATURE OF VIOLET AND PURPLE GROUP—VIOLET FROM RHODAMINE PINK AND WOOL GREEN—PURPLE—TINTS AND SHADES OF VIOLET—CHANGES IN ARTIFICIAL LIGHT.

§ 62. **Orange.**

Orange, being composed of red and yellow, constitutes one of the secondary colours of the Brewster theory. On the spectrum it occupies a place between these two colours, and is somewhat difficult to locate with certainty, as the orange merges into the red on the one hand, and the yellow on the other. The position assigned to normal orange is very slightly beyond the line D, towards the C line (see Fig. 7). A good standard of a full orange colour is seen in the skin of a ripe orange.

For long the dyer and calico printer made their orange colours by the proper mixture of red and yellow, but this is unnecessary now, as the beautiful series of aniline azo oranges, purer than those obtained by admixture, are at his disposal. In making a good orange by admixture, it has already been pointed out (Nos. 3 and 4, Plate V.) that the red should tend to be more of a scarlet than a crimson red, and the yellow should not have a greenish cast: otherwise, a poor quality of orange is obtained by their combination. Many beautiful direct dyeing colours, basic, acid, and azo-orange dyes are employed along with the aniline reds, blues and greens to produce in dyeing a wide variety of useful compound shades of russet, olive, sage, old gold, citrine, etc.

A few of these compound shades are considered under the tertiary colours.

It is an interesting experiment to observe with the pocket spectroscope the formation of an orange by the addition of a little red to a yellow. A solution of naphthol yellow or picric acid gives a beautiful bright yellow, which, on examination with the spectroscope, is seen to consist of red, orange, yellow, yellow green and green rays. If a few drops of a red solution—say 2 R. scarlet or roccelline—be

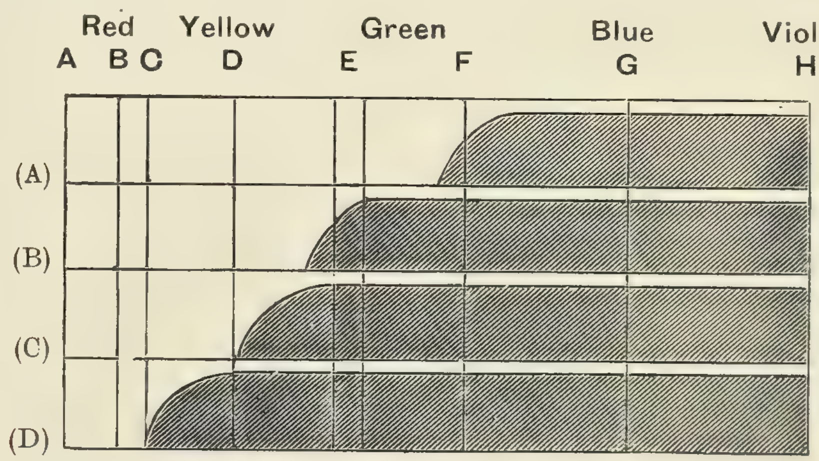


Fig. 35.—Showing the gradual increase in absorption of the spectrum by adding red to yellow to produce orange. (A) represents absorption spectrum of any of the aniline yellow dyes. (B) with slight addition of red. (C) a full orange colour by admixture of yellow and red. (D) represents the absorption of the spectrum where excess of red has been added to the yellow, producing a scarlet, the red and orange rays being alone transmitted.

added to the yellow, it will be observed that the absorption band has greatly increased; the green rays have been absorbed, and the band extends from the violet to the yellow green. If a few drops more of the red solution be added, on viewing again with the spectroscope, the yellow green will now be found absorbed; each little addition of red gradually increasing the absorption of green and yellow green, until only red, orange and yellow are transmitted, which go to produce an orange. If the addition of red be continued, the yellow will also be absorbed until the solution transmits only

red and orange rays, which give the sensation of a scarlet red.

The formation of an orange, as we have described by the gradual addition of a red to a yellow, may be illustrated by the foregoing diagram, Fig. 35, each curve representing the addition of a little red, and showing the gradual increase of the absorption band. Spectrum (A) represents the absorption of naphthol yellow, (B) shows increased absorption on addition of a little red, (C) shows the absorption curve of a full orange colour by admixture of red and yellow, transmitting red, orange and yellow; while curve (D) shows an excess of red added to produce a scarlet colour, transmitting only the red and orange rays from A to C.

Orange, when reduced into tints, gives a soft series of salmon, amber and cream colours, generally termed buffs; while, with black or grey, it produces terra cottas, browns and russet shades (see dyed patterns Nos. 6 and 10 at end of book).

§ 63. **Green.**

The position of pure green on the spectrum is at the two E lines, and extending for a short space on either side of them (see Fig. 7). Thus, if the spectrum from A line in extreme red to H in extreme violet be divided into 1,000 parts, the two lines at E will be found to occupy a position numbering from 638 to 664. According to Prof. Rood, a full green begins at 595 and ends about 682, where the blue green begins; so that the position of a good green may be said to lie at the E lines (see Fig 7, p. 20). In the Young-Helmholtz theory of colour sensation green takes the position of a primary colour; but in the practical theory employed by the dyer and colour mixer it occupies the position of a secondary colour, being formed by the union of yellow and blue.

If blue and yellow lights be combined, white light is

produced, and, as we have already learned (§ 59), yellow in the true scientific sense is not a primary colour, as it is formed by combining red and green lights.

A very good example of a pure green may be found in emerald green with a trace of lemon yellow, and in dyeing a pure bright green is obtained with some of the aniline greenish blues and naphthol yellow. Three parts quinoline yellow and two parts Victoria or acid green dye a beautifully bright tone of emerald green. For a full deep acid green see dyed pattern No. 2 at end of book.

Before the introduction of coal tar colours it was difficult for the textile colourist to produce a brilliant green, for, strange to say, though green is such a universal colour in nature, we have no natural green dyes. The green colouring matter of leaves and plants, *i.e.*, chlorophyll, though it gives a beautiful green colour in alcoholic solution, cannot be employed as a dyestuff. Since the introduction of the aniline greens, yellows and blues, the dyer has a wide variety of colours at his disposal, ranging from yellow greens on the one hand to blue greens, turquoise, cyanine and peacock blues on the other. In commerce the various brands are sometimes designated by a J or a G, *i.e.* (Fr.), *Jeune* = yellow shade, as sulpho-green, J; acid green, JJ; or (Ger.), *Gelb* = yellow, as wool green, G, etc.

The production of a green by the combination of a blue and yellow affords a very interesting and instructive example of a selective absorption, which always arises when two different colours are combined. The true interpretation of this formation of green by mixing blue and yellow we have already fully considered in Chapter IV., § 29. By combining the various aniline greens with orange G., Bismarck brown, fustine or similar red-brown colours, pleasing shades of russet, bronze, olive, citrine, etc., are produced.

Greens, when reduced to form *tints*, give pale tones of

sea green, pea green, etc.; while, with the addition of grey or black, various shades of moss green, sage and myrtle are produced.

§ 64. **Violet.**

The violet-coloured rays, being the most refrangible of all the visible rays of the spectrum, are found at the extreme end of the spectrum, and furthest away from red. If the spectrum be divided into 1,000 parts, starting from extreme red, 0, to extreme violet, 1,000, as shown in Fig. 7, we find that the colour generally termed violet commences very near 800 and extends to 1,000, which is the fixed dark line H.

Violet is a secondary colour in the Brewster, or practical colour theory, as it is compounded of red and blue; but in the true theory of Young and Helmholtz it is regarded more as a primary colour. The sensation of violet, though really a primary and homogeneous colour in the spectrum, is produced by the red and the blue colour nerves being excited, so that the sensation is itself a compound one.

Before the introduction of the beautiful aniline violets, such as the Hofmann and methyl violets, it was impossible to produce by admixture anything like a good pure violet. There were no permanent colours or pigments to represent a good full violet: the nearest approach that could be made was by mixing together ultramarine blue with a little madder pink. The violet of the spectrum, though neither luminous nor brilliant—its luminosity being only 13, compared with red = 1,000, or orange yellow = 7,000—(see p. 70) possesses, nevertheless, the greatest amount of chemical activity or actinic power. The chemical power decreases as the colours approach the red end of the spectrum, where there is an absence of actinic rays. It has been shown also that this same mysterious chemical action present in the violet rays is the cause of the fading or bleaching of

dyed colours on exposure to light. The nearest representation of a full saturated tone of violet representing that of the spectrum is found in some of the pure bluish aniline violets, such as the methyl or Paris violets, or Hofmann's violets, which are the ethyl and methyl derivatives of rosaniline. Formyl violet, 4 B, also gives a good representation of a violet colour.

§ 65. Between a blue violet on the one hand and a red violet or a purple on the other, are a great number of intermediate tones all merging into each other, and it is often difficult to decide when a hue of violet may be called a purple, or a mauve, or a dahlia, as they all merge so closely into each other.

No less than some twenty different hues of violet, or purples, lying between red and blue have been named by Mr. R. Ridgway, an American colourist. He describes them as follows:—

1. Prune.	6. Indian purple.	11. Phlox.	16. Lavender.
2. Dahlia.	7. Royal purple.	12. Pomegranate.	17. Solferino.
3. Auricula.	8. Aster.	13. Mauve.	18. Heliotrope.
4. Plum.	9. Maroon.	14. Magenta.	19. Lilac.
5. Pansy.	10. Violet.	15. Wine purple.	20. Rose.

Even with skilled dyers and colourists there is a wide difference of opinion regarding the true tone of a violet; but, in fact, the same might also be said of a blue, a green, and a red. The ideal standard of one colourist is often not that of another.

If we wish to produce a violet by admixture of blue and red, it must be remembered that the blue must tend towards a violet cast, and the red towards a bluish red or crimson. Vermilion and cobalt blue, for example, or scarlet 2 R. and cyanine blue, when combined, produce very poor, dull violets, owing to the orange being present in the reds, and green in the blues.

This we have already pointed out in Plate V., Nos. 5 and 6, § 52. If, however, we take a blue inclined to violet, such as ultramarine or the azure blues, and combine them with a bluish red like madder lake or acid magenta, then a purer and richer violet is the result.

§ 66. An interesting example of a violet produced by admixture is that obtained by combining magenta, or rhodamine pink with wool green, or any other aniline greenish blue, which absorbs the red and orange rays.

The formation of this violet is interesting from the colourist's and spectroscopist's point of view, as it illustrates clearly

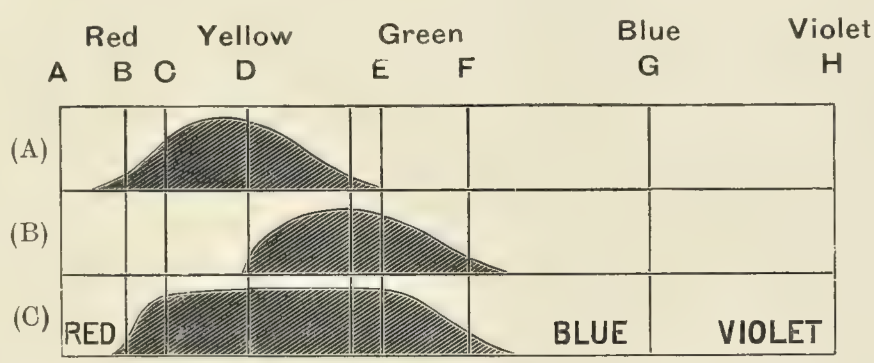


FIG. 36.—This represents the absorption spectra of (A) wool green and (B) rhodamine pink, which, when combined, produce a violet showing the absorption spectrum of (C).

the phenomenon of colour absorption; and also the fact that the colour of a mixture always consists of those rays which are transmitted freely by the component colours.

Thus (A) of Fig. 36 represents the absorption curve of a greenish blue, termed wool green S., showing its absorption of the cherry red at line C, and extending through orange towards yellow at line D, where absorption gradually decreases towards the E lines in green. The colour of wool green, therefore, consists of the extreme red rays and the green, blue and violet.

The beautiful pink dyestuff rhodamine or rosazeine in (B) shows absorption in the brightest part of the spectrum,

i.e., yellow, yellow green and green, while red, orange, blue and violet are freely transmitted. When these two dyestuffs are combined, as at (C), it will be observed that only the extreme red, the blue and violet are transmitted, all the other coloured rays being absorbed in the combination. Thus the absorption spectrum (C) represents that of a violet compounded of wool green and rhodamine pink. If a green dye be used that absorbs all the red rays, a still purer violet will be obtained. The object of the green colouring matter is simply to absorb the red end of the spectrum of the rhodamine, which leaves only the violet end to be transmitted.

In this case the effect produced is exactly the opposite of that mentioned in Chap. VI., § 55, where orange is added to rhodamine to form a scarlet, by absorbing the violet end of the rhodamine spectrum (see Fig. 31).

But no matter how violets are produced by the admixture of two colours, they can never be obtained so pure and saturated as the homogeneous or self colours, derived from aniline. Violets are generally designated as blue violets or red violets by attaching the letters B. or R. to their names. Thus methyl violet B. is a bluish violet; 2 B. a bluer violet; 4 B. a still bluer hue of violet; while fast acid violet 10 B. is indeed a *blue* with a tinge of violet.

In the same way R. represents the tendency towards red; R. violet being a slightly reddish tone; while a 3 or 4 R. violet is a purple, in which the red predominates.

§ 67. Between a violet, where blue predominates, and a purple in which the red predominates, is an intermediate hue, termed mauve, being somewhat redder than violet, but bluer than purple. The term *purple* is itself often used instead of violet, but this is confusing, as the true *purple* is much redder than violet; it can be fairly represented by combining magenta and mauve. The imperial, or *Tyrian*, *purple* of the ancients, which was derived from the shell-fish murex, or

purpura (hence our word purple), was considerably redder in hue than our present-day notion of purple.

As much confusion often arises in naming the various hues in this group of colours, we give here the usual colour terms intermediate between blue and red.

Azure blue.	**Purple.**
Purplish ultramarine.	Wine purple.
Violet.	Crimson.
Mauve.	Magenta.
Dahlia.	**Red.**

§ 68. Tints of violet are known as lavender hues, which are really very light violets of a bluish cast. The tints of reddish violets are termed lilacs, heliotropes or peach blossom. Violet, when mixed with grey or black, gives shades of plum and slate.

§ 69. Colours belonging to the violet class alter greatly in appearance in artificial light. As the ordinary illuminants, such as coal gas, oil lamp, or candle lights, are very poor in blue and violet rays, all violet colours, when viewed in such lights, appear much redder, from the fact that a large proportion of their blue and violet light is quenched, leaving the red in predominance. Hence deep tones of violet appear almost blacks in gaslight, and the lighter tints become changed to pinks and magenta hues.

CHAPTER VIII.

TERTIARY SHADES.

BROKEN HUES—MAROONS—BROWNS—CITRINES AND OLIVES—ABSORPTION SPECTRA OF TERTIARY SHADES—DYED PATTERNS.

§ 70. We come now to consider the large class of shades which contain grey or black in their composition. They may be considered as simply the primary and secondary colours dulled, or what is termed "saddened," with a proportion of grey. We have already explained (Chap. V., § 45) the true constitution of these so-called tertiaries, and shown them to be dulled tones of red, orange, yellow, green blue, and violet. The principal "broken hues," as they are sometimes termed, may be classed as follows :—

When Mixed with Black—

(1) Red	becomes	=	Maroon.
(2) Orange	,,	=	Russet.
(3) Orange yellow	,,	=	Brown.
(4) Yellow	,,	=	Citrine.
(5) Yellowish green	,,	=	Olive.
(6) Green	,,	=	Sage.
(7) Bluish green	,,	=	Blue Sage or Myrtle.
(8) Blue	,,	=	Slate.
(9) Violet	,,	=	Lavender.
(10) Purple	,,	=	Plum.

These broken hues, with their corresponding complementaries or harmonising shades, are given in Fig. 30.

It would be a tedious, as well as a profitless, task to enter minutely into the description of the various methods of producing the many tertiary shades, but we shall choose for our study a few simple and characteristic examples, which will

show sufficiently the nature of all the shades belonging to this large group.

§ 71. In mixing colours to produce soft tertiary shades it is better not to employ clear and decided primary colours, as the slightest excess of any one produces a great alteration in the mixed shade, which causes the colour to be easily put off its desired hue. In practice it is better to employ dull, sad colours when mixing to form delicate compound shades. A slight excess of one or other of the colour ingredients does not then produce such a marked result as when the colours used are bright. Shades, mixed in this way, are easier matched and kept on the proper standard. For example, it is better to employ say Victoria yellow, azo carmine, or azo acid magenta and indigo substitute than the pure and brilliant primaries red, yellow and blue.

There are now at the command of the dyer and textile colourist a great many dyestuffs having beautiful soft shades, which are useful for colour mixing and producing all kinds of shades by admixture, instead of destroying the luminosity and purity of the more expensive primary dyes by combining them together.

In colour mixing and dyeing it is desirable to have as few colour constituents as possible to produce the desired result, as a variety of colouring matters in a certain shade only produces complexity when the shade requires to be matched or altered to a desired standard. No more than three or four colours are necessary to give any shade that is wanted.

All the various tertiary shades merge imperceptibly from the one hue into the other, and hence give rise to innumerable combinations of hue, tint and shade, which are often as difficult to match accurately, as they are to describe or to name.

We shall now proceed to consider briefly the nature of a few of the tertiary shades.

§ 72. *Maroons.*—Pleasing shades of red ranging from a claret and darkening down to a maroon, a puce or red black are obtained by combining red with varying proportions of black or with its complementary green. If the reds have an orange tone, *i.e.*, scarlets, various shades of chocolate and red browns are obtained.

A fine series of darkened reds can be made from fast red or roccelline, or any of the other aniline reds and Victoria or malachite green. Every addition of green to the red pro-

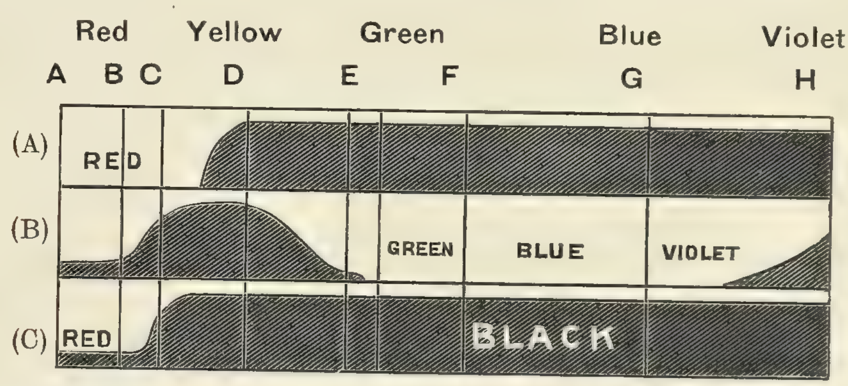


FIG. 37.—Diagram showing how fast red (A) and an aniline green, (B) such as malachite, when combined, produce a claret or maroon, namely, a red of low luminosity, all the other rays being absorbed. The shaded parts represent absorption of light.

duces the same effect as an addition of black. When the red and the green are sufficiently strong there is a complete absorption of all rays, and a black is the result. For an illustration of this see Fig. 15.

To show that a claret, or such shades as are termed cerise, grenadine, garnet, etc., deepening down to a maroon, produced by combining red with green, are simply darkened reds, we may examine the combined spectra of the two colours. In Fig. 37, for example (A) represents the absorption spectra of fast red or roccelline, and (B) that of an aniline bluish green, such as malachite or other benzaldehyde

greens. When these two colours are dyed together or mixed in calico printing, the result represented in spectrum (C) is produced. All the colours of the spectrum are absorbed or quenched, with the exception of the extreme red, producing a red of very low luminosity, and darkened in a manner similar to that produced by adding some black. The shaded portions on the diagram represent, as in all the others, the absorption of colour at those parts of the spectrum.

By making a habit of analysing the formation of shades in this graphic manner, the student may clearly understand the optical structure of all mixed colours.

In a maroon, plum, or claret colour, the red is in excess; but if, while mixing the red and green together, the latter be used in excess, then dull shades of green greys or sages, deepening to greenish blacks, are produced.

The terms plum, maroon and puce, are generally understood to represent respectively a purply black, a crimson black, and a brownish maroon. The term puce is literally "flea colour," from Fr. *puce*, a flea.

§ 73. *Browns.*—If browns be examined with the spectroscope, that they will be found to consist simply of scarlet, or orange rays much diminished in luminosity. They are, in reality, degraded or broken hues of red or orange.

As already shown in Chap. V., § 45, the formula of russet, when analysed, shows it to be a red grey. In our coloured frontispiece we see that orange and violet, when combined, produce russet or red brown.

Orange, as we know, is composed of red + yellow.
Violet ,, ,, red + blue.

So that the symbol for russet would be—using their initial letters—$R_2\ Y_1\ B_1$. When we bear in mind that red + yellow + blue produces grey or black, we find that russet = red + grey. As the red approaches more to a scarlet or orange, the shade

produced on its mixture with grey becomes more of a yellow brown, until it merges into a yellow grey or citrine. See the rich shade of brown, No. 6, of yellow brown, No. 10, and of citrine or olive, No. 5, in the dyed pattern plates at the end of the book.

The great variety of such shades often perplexes the dyer and the colourist in their matching operations.

Beautiful shades of walnut and sealskin browns, ranging to brownish olives, can be made from a combination of sorbine red, orange and wool green.

For example, a fine rich brown is dyed with the proportion of

2 parts orange.
1 part sorbine red.
$\frac{1}{2}$,, wool green.

By varying the proportions of these ingredients three different classes of shades are produced, *i.e.*, those having

A predominance of red	giving	plum tones ; or
,, orange	,,	brown tones ; or
,, wool green	,,	olive tones.

Thus a fine yellow olive is made by using

5 parts orange.
$\frac{1}{4}$ part red.
1 ,, wool green.

and a green olive is made from

4 parts orange.
1 part wool green.

By employing fast yellow instead of orange a beautiful series of neutral greys are obtained. If in such combinations red or orange predominate, a brown is the result ; if yellow be in excess, a citrine or olive is produced ; and if blue predominates, a slate or myrtle green.

Thus in the dyed patterns at the end it is seen that from Victoria yellow, indigo substitute, and azo acid magenta can be produced shades ranging from citrines and browns to

sages and pure greys. No. 5 is an olive. If the red or magenta be in excess a brown is produced as at No. 6, and if orange be in excess a shade of old gold is the result as at No. 10. If green be predominant then a sage is produced as shown in pattern 11. If these three aforementioned dyestuffs be combined in suitable proportions, a beautiful series of pure greys, ranging from a light to a dark grey, can be obtained. These are seen in patterns Nos. 7, 8 and 9.

Rich shades of russet are made by combining methyl violet 3 B. and orange. This is an interesting example of colour absorption, as it shows clearly our case in point, *i.e.*,

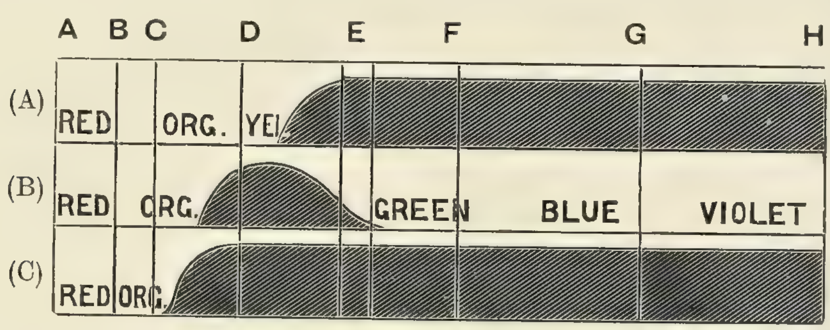


FIG. 38.—Showing the production of a russet shade at (C) by the combination of orange 2, (A), spectrum and methyl violet, (B), (A) and (B), when combined, produce blackness from violet to orange yellow C½ D: thus giving a broken hue of orange red, *i.e.*, russet.

that russet or brown is simply a dull or shaded orange red.

This may be illustrated in a simple manner by using the absorption curves of these two colours and combining them together, as at (C), Fig. 38, when an orange red with all the other rays of the spectrum absorbed is formed. This gives an orange red much degraded with black, or, in other words, a russet or brown shade.

In Fig. 38 (A) represents the absorption spectrum of orange 2, which shows the absorption of all coloured rays from violet at H to the yellow green at D½ E. The red, orange and yellow, being freely transmitted, produce its orange colour.

(B) gives the absorption of methyl violet, showing it to be in the locality of orange yellow, yellow at D, and extending as far as the E lines in green. The green blue, blue and violet are freely transmitted, along with the red and orange rays from A to C$\frac{1}{2}$ D.

When these two dyes are combined the result obtained is shown at (C), where all the rays are absorbed from H in violet to C$\frac{1}{2}$ D in orange yellow, producing a large amount of grey, combined with red and orange. This constitutes the shade of russet produced by combining methyl violet and orange (see also Fig. 39).

Fine shades of russet can be dyed direct from the homogeneous brown dyes, such as vesuvine or Bismarck brown, fast brown, naphthylamine brown, etc.

Russets, when reduced into light tints, give various shades of brown drab, buff, fawn, light amber, and the innumerable class of shades termed warm mode hues.

§ 74. *Citrines and Olives.*—As already shown in § 45, the class of shades known as olives and citrines are composed of green and orange (see Plate I.), and are simply yellows and yellow greens saddened with varying proportions of grey (see Plate IV.). Beautiful shades of olive may be obtained by combining naphthol yellow, wool green and orange; or indeed any of the three dyestuffs employed to make the other tertiary shades, only *the yellow must be the predominating hue* (see Fig. 40). When a pure yellow is saddened down with a neutral grey there is produced a shade of olive which is much greener in hue than what we would generally expect. Indeed it is often difficult to imagine such a shade produced without the addition of a little green. For example, if naphthol yellow be dyed along with a pure neutral tint of grey, such as direct grey, a shade of olive is obtained having a decidedly green hue, similar to that dyed with

yellow orange and a green or blue. To those who have not observed this, it is well worth performing the experiment. We have already learned that a reddish yellow combined with a reddish blue produces an olive or citrine shade (see dyed pattern No. 5 at end, also coloured Plate V.).

§ 75. *Absorption Spectra of Tertiary Shades.*—The following Figs. (39, 40, 41) might be taken to represent three typical absorption spectra of tertiary shades, showing the predominating effect of one of the constituents :—

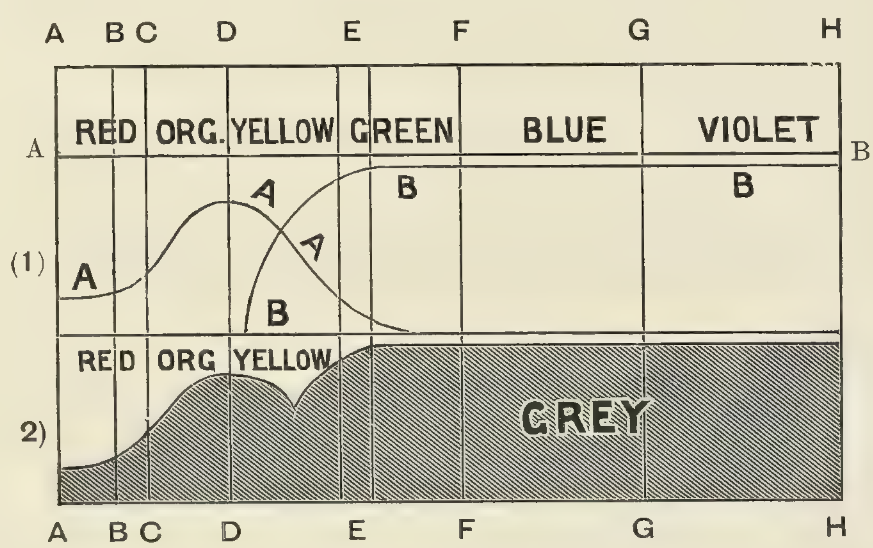


FIG. 39.—Showing the construction of the absorption spectrum of a shade of russet composed of orange G. and victoria blue. Shaded part, Spectrum 2, represents absorption of light.

Fig. 39 (No. 1) is the absorption spectrum of a brown obtained by combining an orange and a blue together.

The line marked A, A, A, is the absorption curve of an aniline blue resembling Victoria blue, and showing absorption in the red, orange, and greatest in the yellow and yellow green, D and D½ E.

The other line, B, B, B, represents the absorption curve of orange G, showing total absorption of the violet, blue and green from fixed lines H to E in green. Absorption gradually decreases towards the D line in yellow.

The line drawn along the spectrum marked A, B, represents the line of total absorption of coloured rays; and where the curves reach up to this line there is total absorption, or blackness in the spectrum.

The spectrum No. 2 is the same as No. 1 above it, but shows the shaded portion of the spectrum where absorption takes place. This shows the shade of russet composed of orange G and aniline blue to be simply red, orange and yellow reflected in small quantity, and mixed with a large proportion of grey, due to the absorption of the coloured rays;—or, in other words, a broken hue of orange red. It

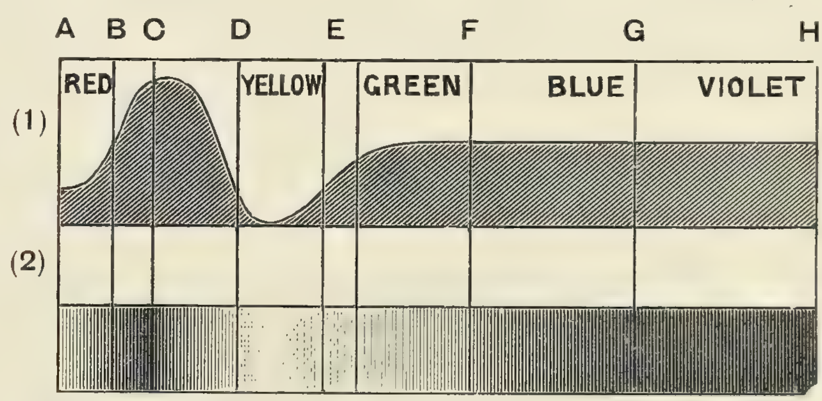


FIG. 40.—Representation of absorption spectrum of an olive made with orange and wool green, the wool green being in excess. The absorption curve in the red is due to the wool green; that extending from the green to violet being the orange. (Shaded portions represent absorption.)

will now be readily seen that the very same shade could also be obtained by simply adding to an orange colour a certain amount of grey or black. The dyed patterns, for example, Nos. 7, 8 and 9, are fine shades of grey produced by the combination of red, yellow and blue. If the red and yellow be in excess, a brown is produced as shown at No. 6. A greater excess of yellow gives the old gold shade at No. 10; while if the green be in excess the sage, No. 11, is produced.

§ 76. Fig. 40 gives a representation of the spectrum of an olive produced by combining wool green and orange, the wool green being in excess.

The strong absorption in the red and orange from lines B to D is due to the wool green; while the absorption curve extending from the E lines in green to the violet is due to the orange constituent. When both are combined it will be observed in diagram 2 that the only rays allowed to pass freely are the yellow rays with a considerable quantity of green, all the others being more or less absorbed, especially the red and orange. This shows that an olive is simply a dulled or broken yellow-green, *i.e.*, a yellow-green mixed with a large proportion of grey caused by absorption.

This may be verified experimentally by dyeing with naphthol yellow and aniline grey, a shade of olive or citrine which matches the one dyed with orange and green.

§ 77. For a final example we may take an interesting case of a dull shade of sage produced by two different methods, *i.e.*:—

1st, by combining = naphthol yellow and methyl violet, and
2nd, ,, = ,, ,, wool green, and a trace of red.

Both of these shades of sage were exactly similar in daylight, but, strange to say, in gaslight they presented an appearance altogether different from each other.

No. 1 shade appeared a *reddish brown* in gaslight, while No. 2 became a *pale olive.*

In order to assist us in the study of this phenomenon we shall represent their constitutions diagrammatically.

No. 1, Fig. 41, represents the absorption spectrum of the sage shade composed of naphthol yellow and methyl violet It shows absorption of the violet and the blue (caused by the naphthol yellow), and absorption of the orange, yellow, yellow green and a little of that green (caused by the methyl violet) This shows the sage colour to be compounded of the red and red-orange rays, with a proportion of the green and blue green.

Diagram 41 shows that the red rays are freely transmitted, and the green rays at E and F are more or less absorbed. This explains the cause of its much redder appearance in artificial lights. Such a shade when dyed on fabrics exhibits strange dichroic properties; its deeper shades appearing much redder than its lighter tints.

Spectrum No. 2 of Fig. 41 represents that of a sage exactly matching No. 1, but composed of naphthol yellow, wool green, and a little red. It will be observed that though the two colours may closely resemble each other when dyed

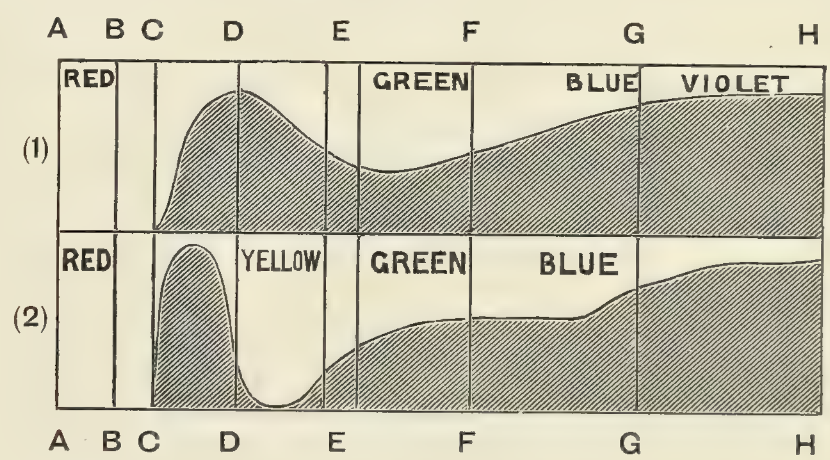


FIG. 41.—Absorption spectra of a sage-green colour. No. 1 composed of naphthol yellow and methyl violet. No. 2, of naphthol yellow, wool green and a little red. Both colours match each other in daylight, but not in gaslight. They have differently constructed spectra.

on wool, their absorption spectra show considerable differences. This spectrum shows strong absorption in the cherry red, C½ D, while the yellow, green, and blue are more readily transmitted than in the case of No. 1. The several individual absorption lines in No. 2 may be traced to the constituent colours; thus the strong absorption in the cherry red is due to the wool green, that in the green and blue is owing more to the presence of the little red, while the strong absorption of cyan blue and violet G, to H, is due to the naphthol yellow. If the absorption curves of these three dyestuffs be superimposed (making the red very dilute) an absorption

spectrum is obtained which corresponds exactly to that of No. 2.

It is readily seen that No. 2 colour shows a much freer transmission of the yellow, yellow-green and blue-green rays than No. 1; hence these two colours differing so widely in optical structure, can never appear identical when examined under artificial illuminants. In this case the green comes into prominence in gaslight, giving the sage shade a greener or more olive hue than its daylight aspect. No. 2 shade shows a greater tendency to reflect the green than the red rays, while No. 1 shows exactly the opposite, having a tendency to absorb the green and reflect or transmit the extreme red.

The light sky blue shown in dyed pattern No. 4, and composed of methyl violet and green, will be found, on examination in gaslight to become very much redder than a similar tone of a pure unmixed blue. Though they may both present an identical appearance in daylight, they will differ widely in hue in gaslight. The non-composite blue appears little changed, but the dyed pattern No. 4 becomes quite a delicate violet or lavender hue.

This, however, touches on the interesting study of colour appearances under artificial lights, and the causes which govern their changes in hue,—a subject which is considered specially in a companion volume on *Colour Matching on Textiles*.

§ 78. Each of the dyed specimens here appended have already been considered in their proper places throughout these pages; but, as these references are necessarily somewhat dispersed, it may be well to refer to them collectively.

DYED PATTERN PLATE 1.

(The weights of dyestuffs mentioned are, in every case, for 100 lb. material).

No. 1 is dyed with :—

Victoria rubine	3 lb.
Orange 2	1 ,,

Victoria rubine, when sufficiently strong, absorbs all the rays of the spectrum except red. If, therefore, it be mixed with an equally strong green, which absorbs all the red rays, then a total absorption of light, or a black is the result, as shown in dyed specimen 3.

No. 2 is acid green (conc.) 4 per cent. This green shows no transmission of the red rays at the strength named, and must, therefore, when combined with Victoria rubine as above, produce the absorption of all coloured rays, or a black.

No. 3. Black produced by the combination of :—

Victoria rubine	2 per cent.
Acid green (conc.)	3 ,, ,,

This shows the total absorption of light as represented in Fig. 15, § 31.

PLATE 2.

No. 4 is a light sky blue of a composite nature dyed with :—

Malachite green	·08 per cent.
Methyl violet	·04 ,, ,,
Vinegar	5 ,, ,,

As shown in Figs. 16 and 33 at § 33, § 61, when violet and green are mixed together, it is found that the blue is the only colour common to them both ; and it is therefore not absorbed. Hence the origin of such composite blues. If the specimen here shown had been dyed much stronger, a deeper and purer tone of blue would have been obtained. Composite blues of this nature change greatly in artificial lights ; and if this dyed specimen be examined in gaslight beside a non-mixed or homogeneous blue of the very same tone of colour, such as cyanine blue, Victoria blue, etc., it will be observed

that the composite blue changes from a sky blue to a delicate lavender; while the other, though matching it in daylight, shows little change.

No. 5 is a citrine dyed with :—

	Grams	or Oz.
Victoria yellow	400	6
Indigo blue substitute B.S.	100	1½

We have already observed (§ 52, Chap. VI.) that a pure tone of yellow and a greenish blue give a good green by admixture. But if the yellow or the blue tend to be of a reddish hue, then the mixture is dulled with grey, caused by the presence of the third primary (red); and, instead of a good green, a broken or saddened green is producd, *i.e.*, a citrine or an olive.

Victoria yellow and indigo substitute B. S. are both of a reddish hue, so that, when they are combined in the dye-bath, or the colour printing paste, a saddened yellow-green or a citrine is produced, as shown in this dyed specimen.

No. 6 is a rich brown or russet dyed with :—

Victoria yellow . . .	2 kilos 200 grams or	2 lb. 3¼ oz.
Azo acid magenta . . .	200 ,,	3¼ ,,
Indigo substitute B.S. . .	200 ,,	3¼ ,,

We have observed in § 73, that when the three above mentioned dyestuffs are combined in suitable proportions, all the coloured rays are quenched or absorbed, and a pure neutral grey is the result (see dyed specimens 7, 8, 9). But if the yellow and the azo acid magenta be in excess, we obtain a broken tone of orange, or a brown, as here shown. If the orange be in great excess, then a clearer orange brown is produced, as shown in dyed specimen 10.

PLATE 3.

Nos. 7, 8, 9, are a beautiful series of greys produced by the combination, in suitable proportions, of the three practical primaries, red, yellow and blue. No. 7 is a light neutral

grey, and by increasing the proportions of dyestuffs a deeper tone of grey is produced as in No. 8, while further addition gives a dark grey, shade 9. These form an excellent series of pure neutral greys which, unlike many similar composite greys, show little or no alteration in hue in artificial light.

They were dyed as follows :—

Dyestuff.	(7) Light.	(8) Mid.	(9) Dark.
Indigo substitute, B.S.	162 grams or $2\frac{1}{2}$ oz.	325 grams or $5\frac{1}{4}$ oz.	650 grams or 10 oz.
Azo acid magenta	62 ,, ,, 1 ,,	125 ,, ,, 2 ,,	250 ,, ,, 4 ,,
Victoria yellow (Meister Lucius & Brüning.)	22 ,, ,, 2 lb. 3 oz. solution.*	50 ,, ,, 5 lb. solution.*	100 ,, ,, 10 lb. solution.*

* Victoria yellow solution 1 per cent., obtained by dissolving 1 lb. dyestuff in 100 lb. water.

PLATE 4.

No. 10 is a fine shade of an orange brown (broken tone of orange) dyed with :—

	grams	or oz.
Orange No. 2	600	$9\frac{2}{3}$
Victoria yellow . . .	200	$3\frac{1}{4}$
Indigo substitute, B.S. . .	90	$1\frac{1}{2}$

It will be observed that in this tertiary shade the orange is in great predominance, so that it is simply an excess of orange + grey (see § 73).

No. 11 is a soft tertiary shade between a sage and an olive produced by greatly diminishing the red or orange in the browns already considered, until the blue and the yellow are in the predominance. It is, therefore, in reality, a broken tone of green, or a green mixed with a large percentage of grey (see § 45, *et seq.*).

It was dyed as follows :—

	grams	or oz.
Victoria yellow . . .	200	$3\frac{1}{4}$
Azo acid magenta . . .	50	$\frac{3}{4}$
Indigo substitute, B.S. . .	250	4

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1.

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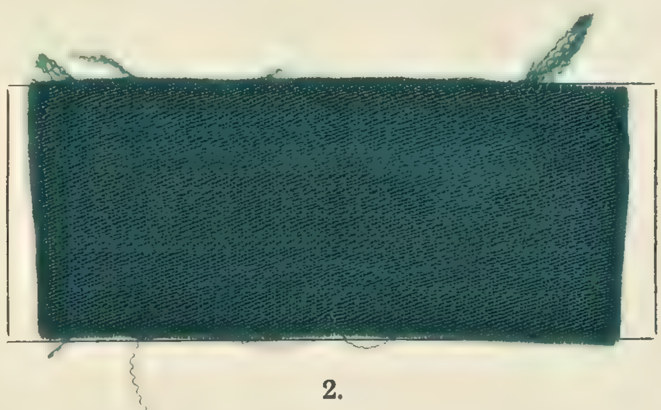
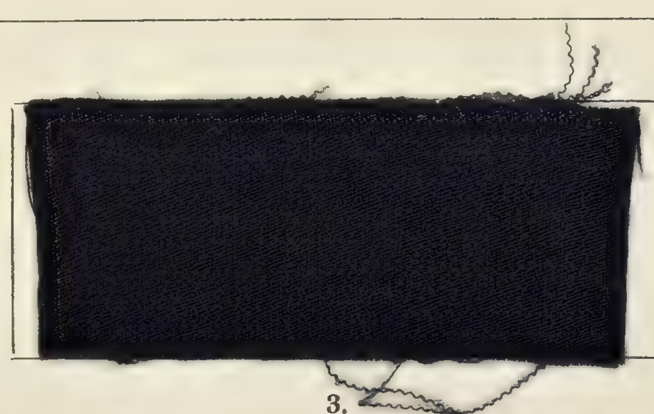


2.

Acid Green (concentrated), 4 per cent.



3.

Victoria Rubine, 2 per cent.
Acid Green, 3 ,,

PATTERN PLATE (2).

(WEIGHT OF DYESTUFFS REFER TO 100 LB. MATERIAL.)

4.

Light Blue, dyed with Malachite Green, ·08 per cent.
Methyl Violet, ·04 ,,
Vinegar, 5·00 ,,

5.

Citrine, from Victoria Yellow, $6\frac{1}{2}$ oz.
Indigo Substitute, $1\frac{1}{2}$,,

6.

Rich Brown, from Victoria Yellow, 2 lb. $3\frac{1}{4}$ oz.
Azo Acid Magenta, $3\frac{1}{4}$,,
Indigo Substitute, $3\frac{1}{4}$,,

PATTERN PLATE (3).

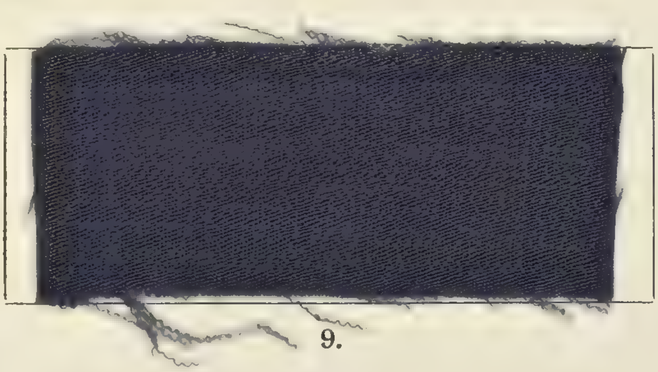
(WEIGHT OF DYESTUFFS REFER TO 100 LB. MATERIAL.)

7.

Light Grey, dyed with Indigo Substitute, 2½ oz.
Azo Acid Magenta, 1 „
Victoria Yellow Solution,* 2 lb. 3 oz.

8.

Mid Grey, dyed with Indigo Substitute, 5¼ oz.
Azo Acid Magenta, 2 „
Victoria Yellow Solution,* 5 lb.



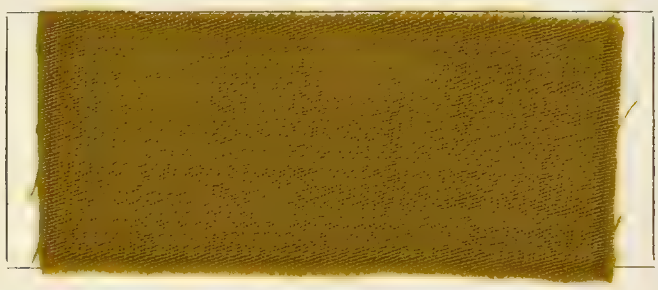
9.

Dark Grey, dyed with Indigo Substitute, 10 oz.
Azo Acid Magenta, 4 „
Victoria Yellow Solution,* 10 lb.

* N.B.—1 per cent. Solution obtained by dissolving 1 lb. Dye in 100 lb. Water.

PATTERN PLATE (4).

(Weight of Dyestuffs refer to 100 lb. Material.)



10.

Brown, dyed with Victoria Yellow, $3\frac{1}{4}$ oz.
Orange 2, $9\frac{2}{3}$,,
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11.

Sage, dyed with Indigo Substitute, 4 oz.
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